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Leak scenarios

TN-4

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Summary

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TN-4

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1 Introduction

NORSOK Z-013 Chapter 7.4.4, Ref. /1/, describes process accidents as a specific category to be analysed in a QRA, but Z-013 does not define a process accident (it refers to the HAZID). Although industry practice is quite consistent, it is observed that there may exist differences in the industry with regard to how "process accidents" are defined by various stakeholders.

To improve consistent application throughout industry, the leak scenarios that are normally considered in Quantitative Risk Analysis (QRA) for offshore oil and gas facilities are defined in this technical note (TN). A leak should fall into only one of the defined leak categories.

These definitions form the basis for leak scenarios included in the leak frequency model.

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

2 Definition of leak scenarios considered in a QRA

This chapter presents the definition of leak scenarios normally included in a QRA.

A leak from the well system is defined as a leak where a hydrocarbon fluid is released through a hole located in the well system (classified as either producing well, gas lift well or injection well in PLOFAM). Leaks from the well system are divided into blowouts and well releases. These releases are further divided into releases during drilling, well operations and releases during normal operation. The following barriers define the process system and the well system in this context:

- Process system and producing well or Injection well:
  - Production Wing Valve (PWV, see Figure 3.1)
- Process system and gas lift annulus:
  - Different configurations are applied in industry (see for instance Ref. /2/), such as annulus wing valve(AWV)/ESV towards topside and Annulus safety valve (ASV) /Annulus safety check valve (ASCV) towards well

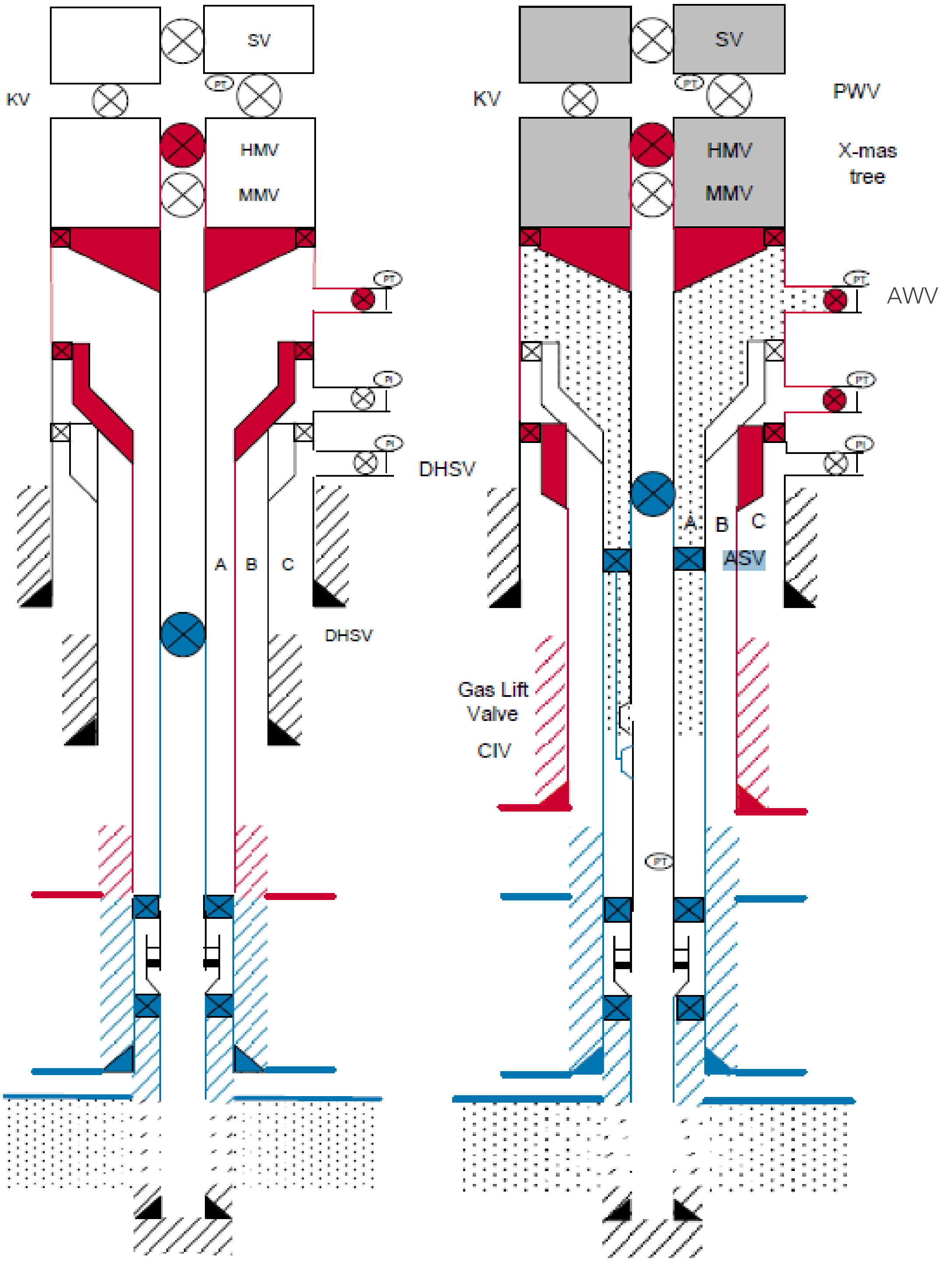

Figure 2.1 - Well barriers schematic for a standard producing well (left) (taken from Ref. /3/ Figure 24), and a gas lift well (right) (taken from Ref. /2/ Figure 1). An item that is coloured red (*e.g.* Hydraulic Master Valve (HMV)) indicate that the item is a secondary barrier element towards the formation fluid, whilst a blue coloured item (*e.g.* Downhole Safety Valve (DHSV)) indicate that the piece of equipment is a primary barrier element towards the formation fluid

2.1.1 Blowout

The definition of a blowout, which is in accordance with Ref. /4/, is as follows:

An incident where formations fluid flows out of the well or between formations layers after all the predefined technical well barriers, or the activation of them, have failed.

Leaks that occur in relation to well intervention operations (e.g. wireline or coiled tubing) are defined to be a blowout if the leak occurs at the reservoir side of the BOP, or if the BOP does not close. Furthermore, leaks that occur during normal operation are defined to be a blowout if the DHSV fails.

2.1.2 Well release

The definition of a well release, which is in accordance with Ref. /4/, is as follows:

An incident where hydrocarbons flow from the well, at some point where flow was not intended and the flow was stopped by use of the barrier system that was available for the well at the time of the incident.

Leaks that occur in relation to well intervention operations (e.g. wireline or coiled tubing) are defined to be a well release if the leak occurs on the platform side of the wireline or coiled tubing BOP, and the BOP is functioning as intended.

During normal production the following (topside) well releases can occur from the wellhead or x-mas tree:

- Producing well/Injection well: Release of fluid from the inventory in the production/injection line between the Downhole safety valve (DHSV, see Figure 1) and the PWV
- Gas lift well: Release of fluid from the annulus inventory between the Annulus Safety Valve (ASV) and the barrier towards annulus topside (*e.g.* EV, AWV) (see Figure 2.1). In cases where no ASV is present, the entire inventory in the gas lift annulus to the GLV may be released (see Figure 2.1). Incidents causing a topside leak from the gas lift annulus where the ASV and the ASCV between gas lift annulus and production string fail, are considered to be a blowout, and therefore not considered as a gas lift well leak. Producing well/injection well/gas lifted well: Release of hydrocarbon fluid from annuli that are not used for gas lift

2.2 Process leak

A process leak is defined as a scenario where fluid from a process system is unintentionally released to the surroundings. The fuel gas system is regarded as part of the process system.

According to this definition, a leak point in a different system than the process system that is being fed by fluid from the process system is a process leak. Examples of such incidents are leaks in utility systems (drain systems, vent system and flare systems). However, if process fluid is released through a hole located in the well system during normal production, the leak is defined to be a well leak (producing well leak or gas lift well leak).

An unintentional release of fluid from a process system to flare tips and atmospheric vents is in general not defined as a process leak except in cases where the release rate exceeds the design specification and poses a fire and explosion hazard to equipment, structures or personnel.

The interface towards the well system is defined in Chapter 2.

2.3 Utility leak

A utility leak is defined as a scenario where fluid from a utility system is unintentionally released to the surroundings. There is no communication with the main process system at any point in time during the time span of the leak. Examples of utility system leaks are:

- Leak of hydraulic oil from a hydraulic system
- Leak of TEG from a TEG system
- Leak of diesel from fuel supply system to a power generation system
- Leak for produced water from a produced water system

Note that the list is not exhaustive.

2.4 Riser leak

A riser leak is a leak that is fed from the riser and/or pipeline system. The leak point is in the riser itself or equipment (e.g. flange, valve) associated with the riser. The boundary between the riser system and the process system is the topside riser ESD valve.

The boundary between the riser system and pipeline system is a subsea valve, the flange connection with the pipeline or a spool piece at the sea bed.

2.5 Pipeline leak

A pipeline leak is a leak that is fed from the pipeline, with or without contribution from riser depending on subsea isolation valve or not is present and functioning. The leak point is in the pipeline itself or equipment (e.g. flange, valve) associated with the pipeline.

The boundary between the riser system and pipeline system is a subsea valve, the flange connection with the pipeline or a spool piece at the sea bed.

If there is no subsea isolation valve segregating the riser and the pipeline, the boundary between the pipeline/riser system and the process system is the topside riser ESD valve.

2.6 Storage tank leak

A storage leak is defined as a scenario where fluid from the storage tank system is unintentionally released to the surroundings.

3 Leak scenarios covered by the model

Chapter 2 defined leak scenarios normally considered in a QRA. Not all of these scenarios are covered by the leak frequency model (PLOFAM). This chapter specifies the leak scenarios covered by the model, which is used to select relevant incidents as basis for frequency estimation and estimation of hole size distributions for the leak scenarios suggested used for modelling in QRAs, given in Chapter 4.

The leak frequency model covers topside hydrocarbon process leaks at NCS. Hence, the leak scenarios covered by the leak frequency model are in accordance with the definition of a process leak as defined in Chapter 2.2. In addition topside leaks from the well system occurring during normal production, as defined in Chapter 2.1.2, are covered by the model. Other leak scenarios, such as leaks from utility systems fed from utility systems (for example diesel from diesel tanks and MEG from MEG-system) are not included.

The leak scenarios covered by the model may have a leak point associated with well systems, process systems or utility systems, and are described in Table 3.1. All leak scenarios normally considered in a QRA (as defined in Chapter 2) and the scenarios covered by the model are visualized in Figure 3.1.

Incidents occurring during well interventions/operations, such as wire line and coiled tubing, are defined as blowouts or well releases, and are covered by Ref. /4/ that is based on the SINTEF Offshore Blowout Database. These incidents are not covered by the model.

The definition of well releases from producing well (with or without gas lift) and injection well during normal production ensures that all recorded topside well releases occurring during normal operation is included in risk assessments based on this model (PLOFAM). Review of recorded leaks from wells during normal production in HCRD and in the SINTEF Offshore Blowout Database has led to the conclusion that the frequency for such incidents given in Ref. /4/, which is based on the SINTEF Offshore Blowout Database, is inaccurate. There are recorded leaks in HCRD that is not found in the SINTEF Offshore Blowout Database. Hence, the frequency for well release during normal production in Ref. /4/ should not be included in risk assessments based on PLOFAM, as this is already included.

The design specification of a vent is exceeded when the released amount generate a fluid concentration that is beyond the hazardous zone classification surrounding the vent. Such incidents are covered by the model. See also Chapter 5.3 for considerations regarding safety design of vents, and how risk associated with vent leaks should be managed.

Table 3.1 - Leak scenarios covered by the model. They occur in well system, process system or utility system (process leaks fed through utility systems). Scenarios that are not listed in this table are not covered by the model

Leak point in well system	Leak point in process system	Leak point in utility system
1. Producing well/Injection well: Topside well release where the inventory between DHSV and PWV is released during normal production. 2. Gas lift well: Topside well release where the inventory between the ASV and the barrier towards the process system is released. In cases where no ASV is present, the entire inventory in the gas lift annulus to the ASCV may be released. Assuming that the check valve ASCV is functioning, otherwise there is no barrier towards the reservoir. 3. Release of hydrocarbon fluid from annuli that are not used for gas lift	4. Leak point in process system between PWV and topside riser ESDV/-storage ESDV. The fuel system is regarded as part of the process system.	5. Leak point in flare system (low pressure or high pressure flare system) 6. Excessive releases through flare tips and atmospheric vents that exceed the design specification and pose a fire and explosion hazard to equipment, structures or personnel. Such leaks are denoted vent leaks (see also Chapter 5.3). 7. Leak point in utility systems that is fed by hydrocarbons stemming from process system. Systems covered by the model are: a. Open drain system b. Closed drain system c. Chemical injection systems d. Produced water

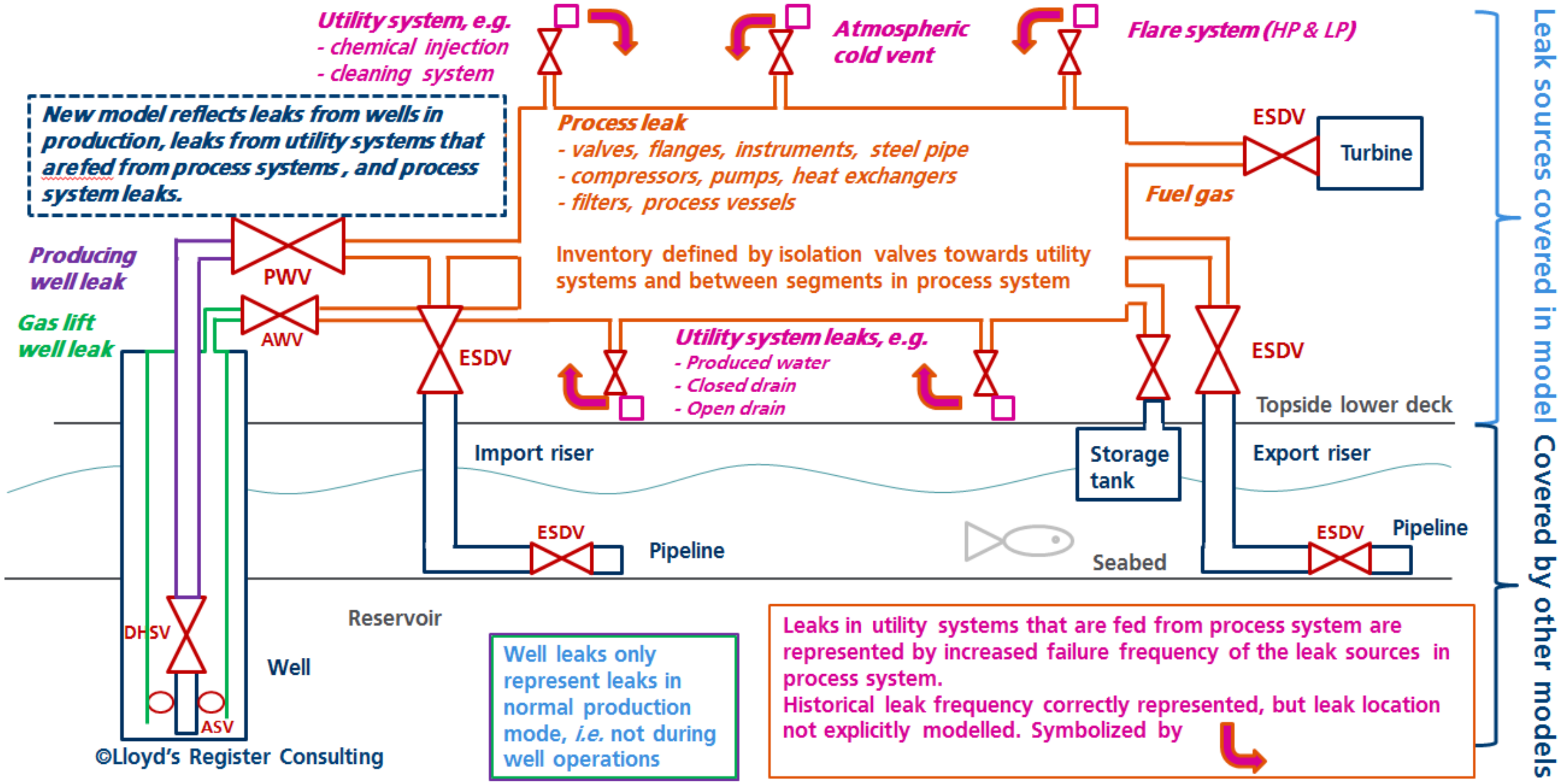

Figure 3.1 - Illustration of leak scenarios normally considered in a QRA (Ref. Chapter 2). The figure shows which scenarios that are covered by the model and which that are not

4 Leak scenarios modelled in QRAs

The description of leak scenarios covered by the model, described in Chapter 3, gives guidelines for selection of relevant historical incidents in the data used as basis for estimation of leak frequencies and hole size distributions for process leaks and well releases during normal operation. In other words, historical incidents that fall within one of the leak scenarios given in Chapter 3, form the basis for frequency estimation and estimation of hole size distributions for the leak scenarios modelled in a QRA. The leak frequency model has to define leak scenarios relevant for QRAs that captures the important risk contributing leak scenarios (given in Chapter 3), and where leak frequencies can be estimated based on available data material. This chapter defines leak scenarios suggested for leak modelling in QRA's performed for oil and gas facilities at NCS. The leak frequency model gives leak frequencies and hole size distributions for the leak scenarios defined in this chapter (see TN-6), which covers the leak scenarios described in Chapter 3.

Three main leak scenarios for modelling in QRAs are defined for the leak frequency model. That is *Process leak*, *Producing well leak* and *Gas lift well leak*. Further details and recommendations with respect to modelling in QRAs are given for these scenarios in Chapter 4.1, 4.2 and 4.3, respectively.

0.1 kg/s is recommended as leak rate threshold for estimation of leak duration (both in terms of calculation of fluid dispersion and fire duration) in a QRA, for all leak scenarios in open areas and leaks in enclosures having a net volume more than 1,000 m^3 and with ventilation rate of 12 ach or higher. This is explained in detail in Chapter 4.4.

Chapter 4.5 describes the rational for the lower boundary with regard to aggregated released amount of hydrocarbons (10 kg). The model distinguishes on leak scenarios where the total released amount of hydrocarbons is ≤10 kg, and >10 kg. These leaks are classified as *Marginal leaks* and *Significant leaks,* respectively.

In total six leak scenarios for modelling in QRAs are defined, that are summarized in Table 4.1, and Figure 4.1. The table also shows which leak scenarios in Table 3.1 that are put as basis for estimation of leak frequencies and hole size distributions for the six defined leak scenarios for the model. In a QRA the risk, in terms of fire- and explosion load exposure to vulnerable equipment and structures such as safety systems, pressurized equipment, load carrying structures and main safety functions, associated with Marginal leaks can be neglected. However, the risk to personnel associated with Marginal leaks should not be neglected. This is further described in Chapter 4.5.

The model does not give separate leak frequencies for scenarios where the initial pressure is different from the operational pressure. The initial pressure must be assessed as part of the QRA, but normally the initial pressure is assumed equal to the operational pressure. This is further discussed in Chapter 5.1. Furthermore the model does not give generic frequencies for limited leaks (as defined in Ref. /8/), which is discussed in Chapter 5.2. Finally, even if recorded incidents of releases through vents that represented a potential major accident hazard have been included as part of the validation of the model to account for the underlying generic risk associated with such events (see TN-3), this does not mean that the model accounts for the risk associated with improper safety design or operation of such systems for a specific installation. This is further explained in Chapter 5.3.

Release of hydrocarbon fluid from annuli that are not used for gas lift (Scenario 3 in Table 3.1), is not suggested included as a separate scenario for QRAs. Instead these scenarios are included as part of the frequency for producing well leaks and gas lift leaks.

Table 4.1 - Defined leak scenarios for QRAs

Modelled leak scenario		Leak scenarios included
Process leak	Significant	Scenario 4-7 in Table 3.1, released quantity >10 kg
	Marginal	Scenario 4-7 in Table 3.1, released quantity ≤10 kg
Producing well leak[1]	Significant	Scenario 1 and 3 in Table 3.1, released quantity >10 kg
	Marginal	Scenario 1 and 3 in Table 3.1, released quantity ≤10 kg
Gas lift well leak	Significant	Scenario 2 and 3 in Table 3.1, released quantity >10 kg
	Marginal	Scenario 2 and 3 in Table 3.1, released quantity ≤10 kg

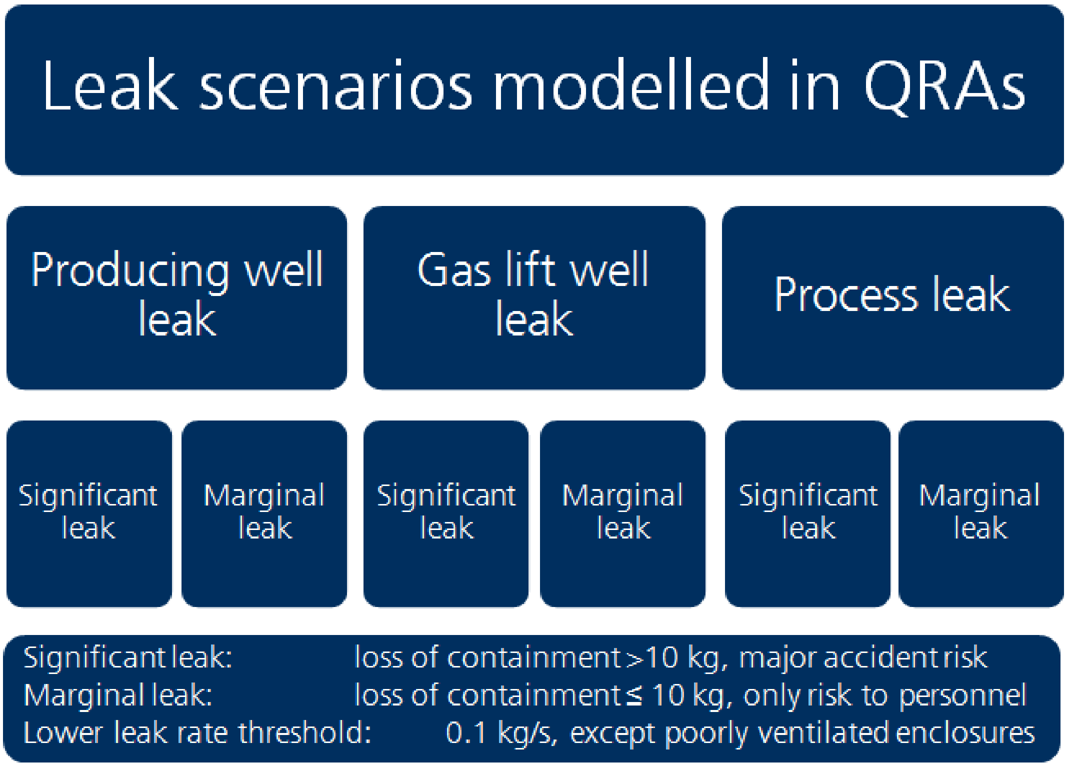

Figure 4.1 - Illustration and summary of the leak scenarios to be modelled in a QRA

4.1 Process leaks

As defined in Table 4.1, Process leaks cover leak scenario 4-7 in Table 3.1. Note that the leak frequency for process leaks estimated by the model does also account for leaks occurring in the utility system, but being fed from the process system. This is done by including process leaks fed through utility systems, but not equipment counts from utility systems as basis for the model validation. This implies that utility equipment should not be counted as basis for estimation of process leak frequencies. Furthermore the model does not give separate leak frequencies for process releases through utility systems and through process system. This means that the QRA, based on the frequency model, will not reflect the potential location of the leak sources, and that the leak frequency contribution from utility systems will scale with the number of equipment counts for process system.

[1] The frequency for producing wells and injection wells are assumed to be identical. The leak scenario is denoted producing well only

Significant process leaks should be modelled as full pressure leaks, i.e. normal operational conditions should be assumed. The released amount is restricted by the emergency shutdown system (ESD system) and blow down system (BD system) if such systems are in place and functioning as intended. The time to initiation of these systems are to be defined in the QRA, and based on that the leak duration and released quantity should be estimated as part of the QRA.

4.2 Producing well leaks

As defined in Table 4.1, Producing well leaks cover leak scenario 1 and 3, in Table 3.1. A significant producing well leak should be modelled as a full pressure topside well release of the inventory between the DHSV and PWV at normal operational conditions. The released amount is restricted and controlled by the DHSV towards the well (which is closed from the onset of the leak). On the downstream side the segment will be controlled by the PWV. The time to closure of the DHSV and PWV is to be defined in the QRA.

Producing well leaks and gas injection well leaks are modelled equally, and the leak frequencies for these wells are judged to be identical.

4.3 Gas lift well leaks

As defined in Table 4.1, Gas lift well leaks cover leak scenario 2 and 3 in Table 3.1. A Significant gas lift well leak should be modelled as a full pressure topside well release where the inventory between the ASV and the barrier towards the process system is released. In cases where no ASV is present, or the ASV is not functioning, the entire inventory in the gas lift annulus may be released. Thus, the released amount is restricted and controlled by the ASV towards the well if present/functioning. Otherwise the check valve ASCV is the only barrier towards the well, if functioning. If the check valve is not functioning and the ASV is not present/functioning there are no barriers towards the well. On the upstream side the segment may be controlled by the Annulus Wing Valve (AWV), Annulus master valve or topside ESV. In addition, it could also be controlled by the emergency shutdown system (ESD system) and blow down system (BD system) if such systems are in place, they are functioning as intended, and are connected to the gas lift system. The time to initiation of all these systems is to be defined in the QRA.

4.4 Initial leak rate boundary for leaks considered in a QRA

The lower initial leak rate boundary suggested for quantitative risk analysis that is used as basis for the definition of Marginal leaks (see Chapter 4.5) is set to 0.1 kg/s for typical offshore process modules. The initial leak rate is the leak rate at the onset of the leak (t = 0). This is in accordance with industry practice in Norway (Ref. /1/). The threshold is in accordance with the threshold for reporting of leaks to the Petroleum Safety Authority in Norway.

The associated limitation with regard to geometry is stated below, *i.e.* the validity of the term "typical offshore process module".

The threshold of 0.1 kg/s is based on the following:

- The generated volume of the flammable cloud from a stationary 0.1 kg/s leak is less than 1 m^3 (calculated in Phast) except cases where the natural ventilation is poor and the module volume is small. A flammable volume of 1 m^3 implies an insignificant probability for delayed ignition caused by exposure to objects intended for use in explosive atmospheres. The basic ignition probability per m^3 free flow volume is according to the MISOF ignition model (Ref. /5/) $8.0 \cdot 10^{-6}$ per m^3 exposed to flammable gas for 5 minutes
- The generated explosion loads in case of ignition of a flammable volume of 1 m^3 is considered negligible except in marginal enclosures (see below)

- The flame length generated from a 0.1 kg/s leak is about 5 meter. The probability for exposure to neighbouring equipment causing rupture of the exposed equipment is considered to be significant, but small. 0.1 kg/s is defined as the lower cut off in Ref. /6/. The probability for immediate fatal exposure to personnel is considered to be small for such fires
- The probability for immediate ignition of a 0.1 kg/s release is small. According to the MISOF ignition model (Ref. /5/), the immediate ignition probability is 0.00015 for all types of equipment types. For pumps, an additional ignition probability of 0.007 applies

Leaks less than 0.1 kg/s may in some cases constitute a significant risk, and should be considered in such cases. An example of such a situation is enclosures, where leaks less than 0.1 kg/s is likely to constitute a significant risk contribution (Ref. /7/). This applies in particular to explosions, but also the consequences from fires may become severe in such cases, in particular with regard to exposure to personnel as the entire enclosure may be exposed to intolerable fire loads (which will depend on the available air for the combustion process). Explosions in such enclosures may give fragments resulting from disintegration of the enclosure itself causing escalation and fatalities to personnel in the vicinity of the enclosure. In addition, a hydrocarbon fluid concentration close to the flammability range may be fatal due to asphyxiation. Such concentrations may arise quickly in small enclosures. Lastly, the leak statistics shows that operational causes are dominant, which means that in many cases personnel are present at the scene of the leak, for instance occurring due to improper operation. The combined effect of personnel being present inside the enclosure and the quickly arising accidental loads thus should be considered for incidents enclosures.

Based on the above discussion, the lower initial leak rate boundary for small enclosures should be evaluated specifically in each case.

The 0.1 kg/s boundary applies for leaks in enclosures having a net volume more than 1,000 m^3 and with ventilation rate of 12 ach or higher. The volume in this context is the free flow volume within the boundary of the area being studied (*e.g.* walls, ceiling and floor). For enclosure volumes less than 1,000 m^3 and/or smaller natural ventilation rates than 12 ach, initial leak rates less than 0.1 kg/s may generate a significant flammable cloud. The housing around compressors for noise protection is one example of a small enclosure that may have a net volume less than 1,000 m^3.

The relation between enclosure volumes, leak rate, forced ventilation rate and resulting average steady-state gas concentration inside an enclosure is shown Figure 4.2. Figure 4.3 gives the resulting total mas of gas in the enclosure. The calculation of the relations is based on the following properties of the natural gas:

- Density: 0.76 kg/m^3
- Lower Flammability Limit: 4 vol% (= 0.03 kg fuel per m^3 given a fuel density of 0.76 kg/m^3)

The leak frequency model can be used to estimate the frequency for leaks having an initial leak rate less than 0.1 kg/s, but the results should be interpreted in light of the fact that model validation has been focusing on leaks having an initial leak rate greater than 0.1 kg/s. Special considerations may therefore have to be performed in each case.

The maximum initial leak rate should be assessed based on the frequency of full rupture and properties of the system being studied.

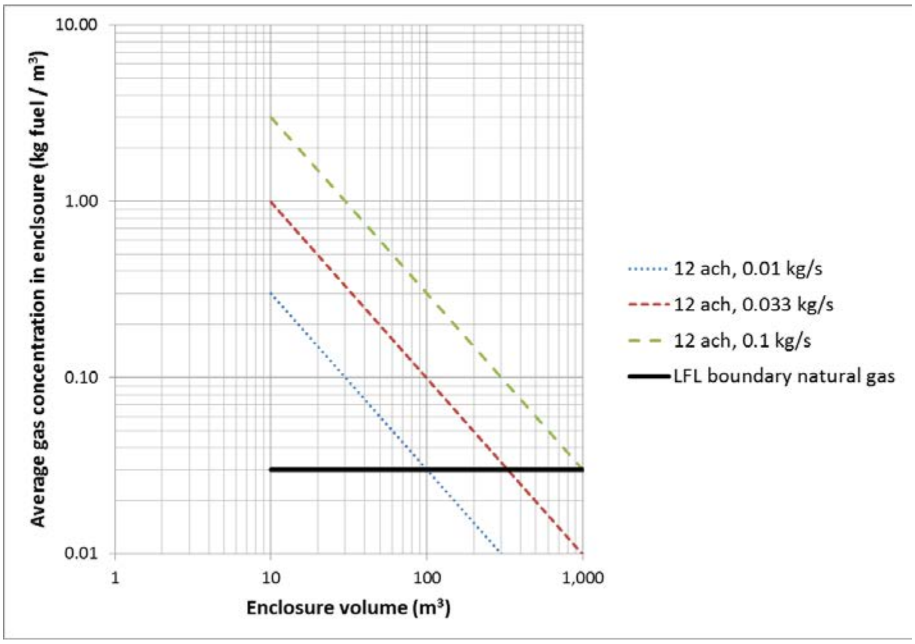

Figure 4.2 - Average steady-state gas concentration in enclosure as a function of enclosure volume for three different constant leak rates

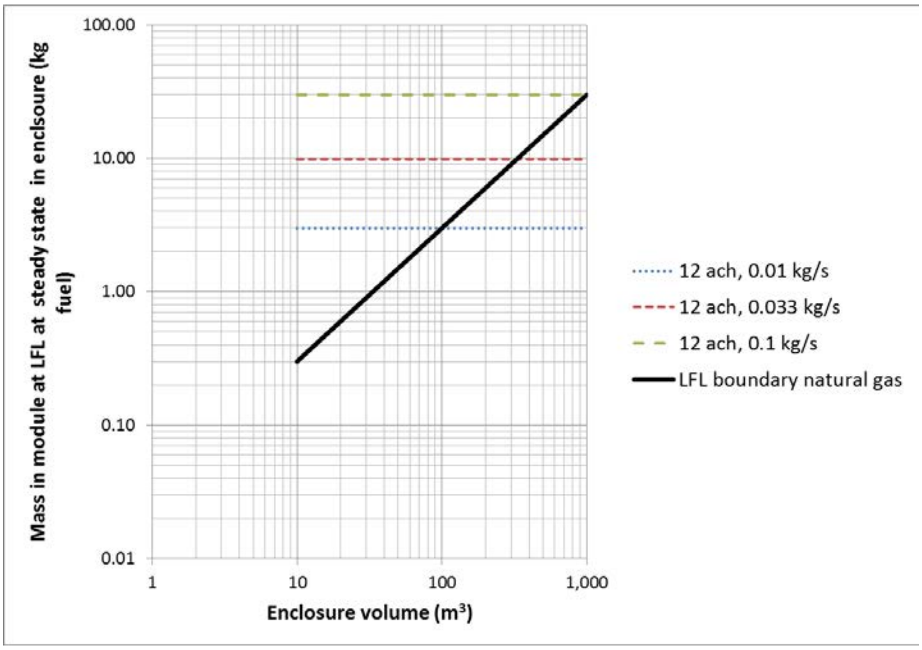

Figure 4.3 - Mass gas in module at LFL at steady-state condition in enclosure as a function of enclosure volume, given for three different leak rates. In addition the mass gas in enclosure if the gas concentration= LFL, is given as a function of enclosure volume

4.5 Significant leaks vs. Marginal leaks

As described above, Marginal leaks are defined as leak scenarios where the total released amount of hydrocarbons is ≤10 kg, while Significant leaks are defined as leak scenarios where the total released amount of hydrocarbons is >10 kg. This is based on the lower boundary with regard to aggregated released amount of hydrocarbons, which is set to 10 kg for typical offshore process modules. The boundary applies with regard to calculation of risk in terms of exposure to vulnerable equipment and structures such as safety systems, pressurized equipment, load carrying structures and main safety functions. Marginal leaks will not impair these safety functions/objects, and do only pose a risk to personnel.

The threshold of 10 kg follows from:

- The longest duration of a marginal leak down to the lower initial leak rate boundary (0.1 kg/s, see Chapter 4.4) becomes 100 seconds (10 kg divided by 0.1 kg/s), which only will in very unfavourable conditions have sufficient duration to cause rupture of pressurized equipment and/or impair to safety critical equipment. Furthermore, the probability for exposure to vulnerable equipment in such a scenario is considered remote
- The largest possible combustible cloud resulting from an instantaneous release of 10 kg will generate marginal explosion loads. Assuming that 50 % of the amount (5 kg) is forming a cloud having a homogenous concentration somewhat above than the lower flammability limit (0.05 kg/m^3) gives a gas cloud with a volume of 100 m^3 (which is considered to be an upper estimate). The resulting combustible fluid for such releases is expected to in the range 10 – 100 m^3. A cloud having a volume of 10-100 m^3 will in typical offshore process modules generate marginal explosion loads. However, for small enclosures this should be investigated specifically according to below
- A flammable volume of 100 m^3 (or significantly less in most cases) having a short duration implies an insignificant probability for ignition due to exposure to objects intended for use in explosive atmospheres (that potentially possess a failure mode that cause ignition upon exposure). The basic ignition probability per m^3 free flow volume is according to the MISOF ignition model (Ref. /1/) $8.0 \cdot 10^{-6}$ given 300 seconds exposure time
- An instantaneous release of 10 kg may expose internal escape ways inside the area where the leak occur and in some cases also external evacuation routes to the evacuation means. The exposure time of intolerable fire loads would be very short, and will in practice have no significance for the actual performance of the evacuation ways to mustering area/life boats

The threshold does not apply for exposure to personnel. The leak statistics shows that operational causes are prominent. In some of these cases, personnel were present at the scene of the leak, which should be reflected in the consequence model.

According to available leak statistics, the number of leaks where the released amount is less than 10 kg is significant. Examples of such scenarios are:

- A leak caused by erroneous opening of a valve that is closed immediately upon detection by the operator of the valve (either at location or remotely by operator in control room)
- A leak point arising in an isolated segment of the process system (*e.g.* unintentional leak of small amount of pressurized gas inside valve house when valve drain plug is opened in initial stage of valve maintenance operation)

The causes for marginal leaks could be both technical and related to activity (e.g. maintenance), but it is judged that activity is a dominant factor, and probably greater than for significant leaks. Hence, it is reasonable to argue that the actual underlying frequency for marginal leaks will be specific to platform specific organisational factors. The estimate for marginal leaks provided by the model is generic and cannot be adjusted according to installation specific properties. This means that the frequency for marginal leaks should not be broken down into sub categories of incidents in terms of causes or successful vs. non-successful operator intervention. The estimate is to be considered generic, and should only be combined with an analysis of the ignition control barrier (i.e. to set the ignition probability) and the consequences to personnel.

In order to estimate the fire frequency, it is recommended to use the stated probabilities for immediate ignition in the MISOF ignition model (*i.e.* P_{im} and $P_{im,pump}$). This does not mean that the analysis does not have to confirm that delayed ignition can be neglected.

As for the lower initial leak boundary, the boundary of 10 kg for marginal leaks does not apply for enclosures having a net volume less than 1,000 m^3. Further description of the basis for this limitation can be found in Chapter 4.4. Small enclosures are common at installations at NCS. Risk related to explosions in such enclosures (i.e. < 1000 m^3) should be carefully evaluated, as ignition probability is high (Ref. /5/), and the required leak rate and/or total leaked mass to form an ignitable cloud in small enclosures are small. Explosions in such enclosures may give fragments causing escalations and fatalities to personnel in the vicinity.

5 Leak scenarios not covered by the model

Zero pressure leaks and limited leaks are leak scenarios that have been frequently used in the industry, as process leaks were divided into Full pressure leaks, Limited leaks and Zero pressure leaks in the previous model, Ref. /8/. This is illustrated in Figure 5.1. Significant process leaks as defined in this model are modelled similar as Full pressure leaks in the previous model (see Chapter 4.1). Limited leaks and zero pressure leaks are not included in PLOFAM. The reason is explained in Chapter 5.1 and 5.2 below.

Considerations regarding safety design of vents and how risk associated with vent leaks should be handled in a QRA are given in Chapter 5.3.

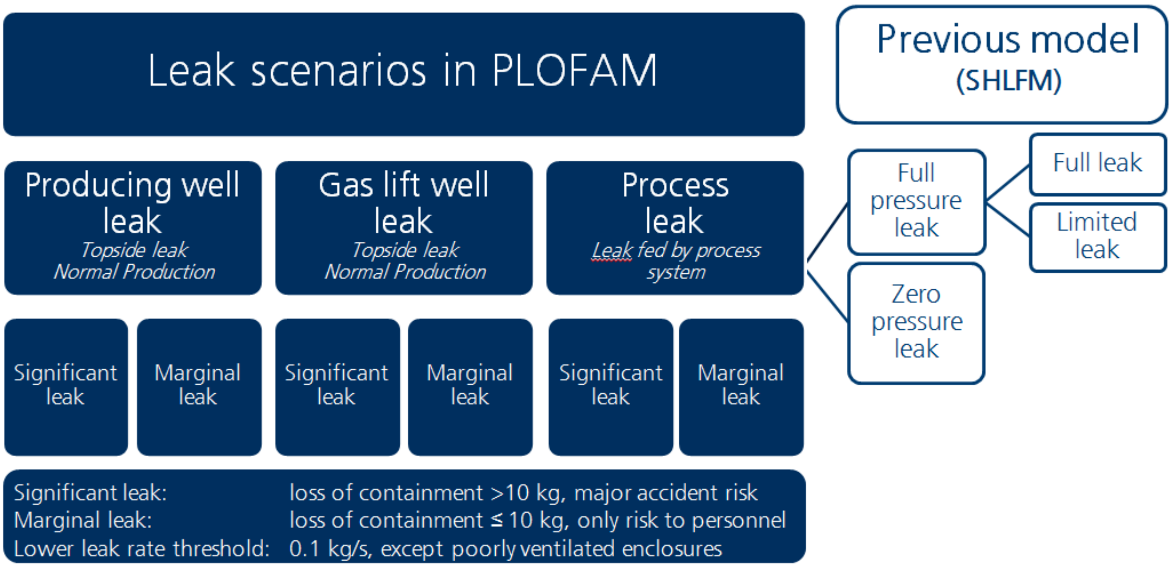

Figure 5.1 - Illustration and summary of the leak scenarios to be modelled in a QRA, together with the leak scenarios Full pressure leaks, Limited leaks and Zero pressure leaks defined in the previous model. Previous model refers to SHLFM Ref. /8/

5.1 Zero pressure leaks

Zero pressure leaks are in Ref. /8/ defined as scenarios where the overpressure is virtually zero (0.01 barg or less). This may be because the equipment has a normal operating overpressure of zero (e.g. open drains), or because the equipment has been depressurised for maintenance. Figure 5.2 and Figure 5.3, gives the fraction and number of leaks that were classified as Limited leaks, ESD isolated leaks, Late isolated leaks and Zero pressure leaks in Ref. /8/, that in PLOFAM is classified as Marginal leaks (<10 kg) and Significant leaks (>10 kg). Only leaks that were included both in Ref. /8/ and in this analysis are included. 4.4 % were classified as Zero pressure leaks, where 2.6 % of these are in PLOFAM classified as Marginal leaks. Due to the small fraction of Zero pressure leaks with a released quantity above 10 kg, and the small risk contribution from zero pressure leaks, zero pressure leaks are in PLOFAM included as process leaks, i.e. handled as process leaks with back pressure similar to the operating pressure. Hence the model does not give separate leak frequencies and hole size distributions for zero pressure leaks, as defined in Ref. /8/.

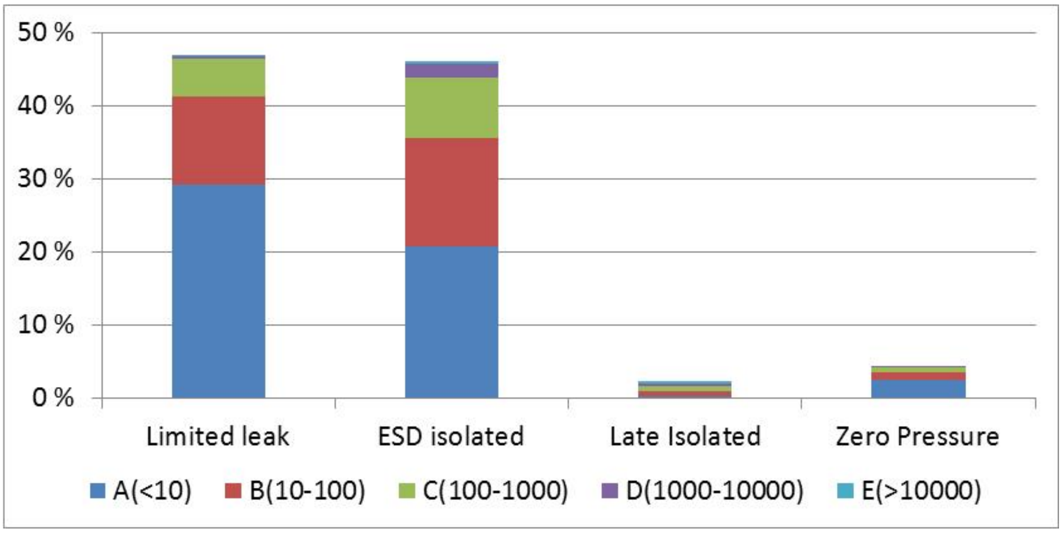

Figure 5.2 - Fraction of leaks that were classified as Limited leaks, ESD isolated leaks. Late isolated leaks and Zero pressure leaks in Ref. /8/, that in PLOFAM is classified as Marginal leaks (<10 kg) and Significant leaks (>10 kg)

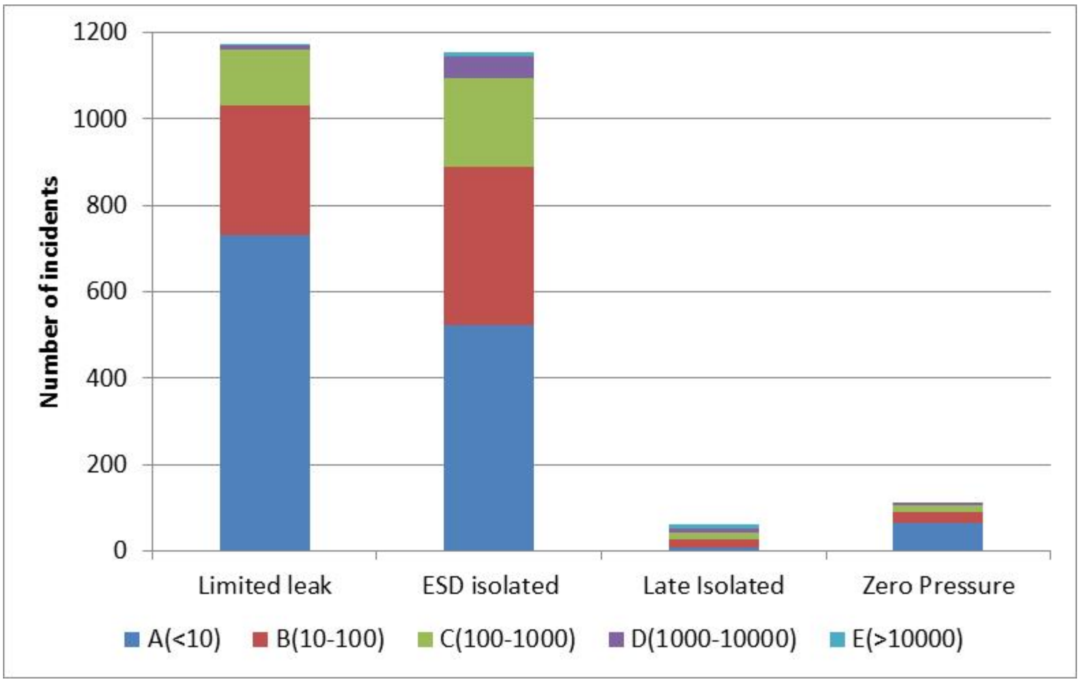

Figure 5.3 - The number of leaks that were classified as Limited leaks, ESD isolated leaks. Late isolated leaks and Zero pressure leaks in Ref. /8/, that in PLOFAM is classified as Marginal leaks (<10 kg) and Significant leaks (>10 kg)

5.2 Limited leaks

Limited leaks are in Ref. /8/ included to take into account scenarios that have a reduced released quantity and/or a reduced duration (compared to process leaks as defined in Chapter 4.1) due to:

2. Restrictions in the flowline.
3. Operator intervention (valve closed by operator intervention)
4. The leak is at a favourable location in terms for pressure conditions. This is relevant for liquid releases if, for instance, the leak point is above the lowest point in the segment, or the amount of liquid is limited by high points in the segments

In addition it is reasonable to believe that many of the limited leaks have occurred in connection with human operations. In these cases the released quantity may be significantly reduced (as compared to a Process leak as defined in Chapter 4.1), as the volume and/or pressure is likely to be less than at normal operation. In case of leaks caused by human operations, recorded incidents have demonstrated that the leak is often terminated by the operator (for example if a valve is opened erroneously, it can be closed by the operator within a short time). These leaks are likely to be classified as marginal leaks using the suggested leak scenario definitions in this technical note. Figure 5.4 gives the fraction of leaks that were classified as Limited leaks, ESD isolated leaks, Late isolated leaks and Zero pressure leaks in Ref. /8/, that in PLOFAM is classified as Marginal leaks (<10 kg) and Significant leaks (>10 kg). Figure 5.5 gives the fraction of leaks that in PLOFAM is classified as Marginal leaks (<10 kg) and Significant leaks (>10 kg) that in Ref. /8/ were classified as Limited leaks, ESD isolated leaks, Late isolated leaks and Zero pressure leaks. From Figure 5.4 it is seen that 62 % of the Limited leaks are in PLOFAM classified as Marginal leaks. Thus the remaining 38 % that were classified as Limited leaks that are now modelled as significant process leaks, were probably classified as limited leak due to one of the above reasons (point 1-3 above). It is however not recommended to model limited leaks on a general basis in QRAs based on this. Instead it is recommended that other physical restrictions in the process system than the ESD and PSD valves, such as check valves, gravity (high leak points or high points for oil leaks) and other flow restrictions should only be reflected if an explicit model of the system is established. The properties of the restrictions including reliability, if relevant, must be described as part of the analysis, and should also include human interventions.

The duration of limited leaks follows from the developed specific model of the process system accounting for the actual flow restrictions.

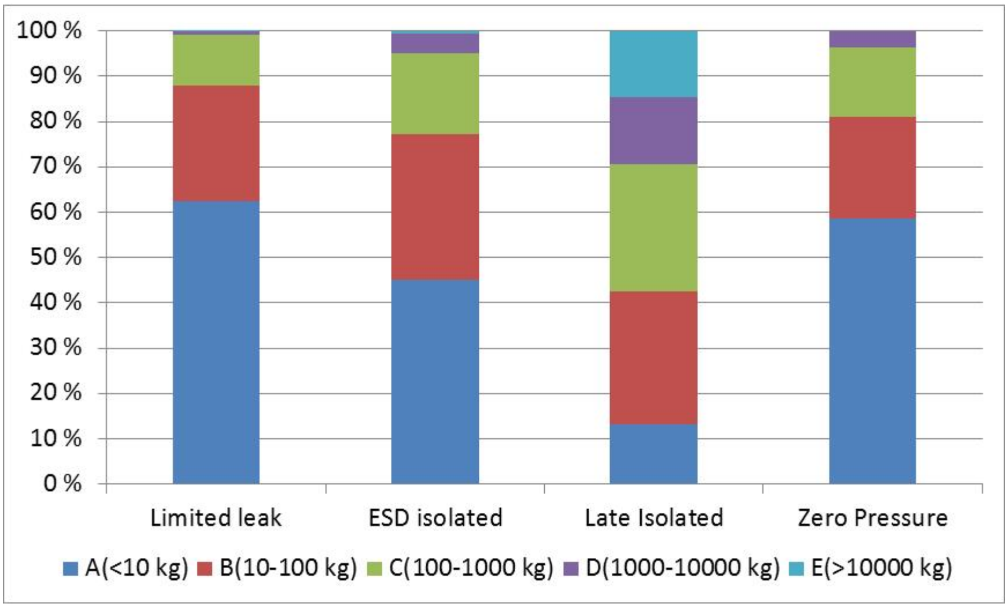

Figure 5.4 - Fraction of leaks that were classified as Limited leaks, ESD isolated leaks, Late isolated leaks and Zero pressure leaks in Ref. /8/, that in PLOFAM is classified as Marginal leaks (<10 kg) and Significant leaks (>10 kg)

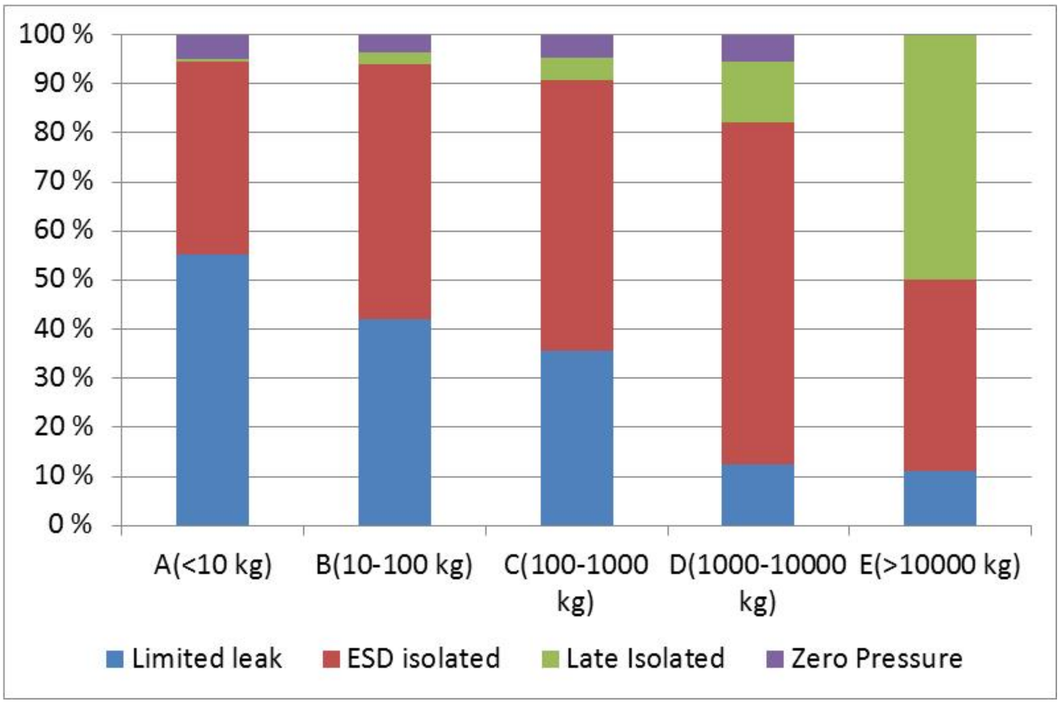

Figure 5.5 - Fraction of leaks that in PLOFAM is classified as Marginal leaks (<10 kg) and Significant leaks (>10 kg) that in Ref. /8/ were classified as Limited leaks, ESD isolated leaks, Late isolated leaks and Zero pressure leaks

5.3 Vent leaks within design specification

Excessive releases through flare tips and atmospheric vents that exceed the design specification and pose a fire and explosion hazard to equipment, structures or personnel are included in the model. However, vent leaks where the release is within the design specification are not included.

In general, the safety design of vents is to be verified through other safety studies than the QRA. Such studies include Hazard Operability Studies and specific assessments of the dispersion of the fluid being released.

The safety design of the vents should be raised in the hazard identification process in a QRA where the leak frequency model is applied. If there are known design issues with vent systems, specific assessments should be performed (for example reliability of systems preventing overfilling diesel tanks). The result should be considered included in the QRA if no technical solution that rectifies the issue is found and the risk is judged to be significant. A generic frequency for vent leaks that represent a significant risk is however not meaningful in the context of a QRA, *i.e.* providing additional information on how to control the risk associated with such systems.

Recorded incidents of releases through vents that represented a potential major accident hazard have been evaluated as part of the project (see TN-3). Such known incidents have been included as part of the validation of the model to account for the underlying generic risk associated with such events. However, this does not mean that the model accounts for the risk associated with improper safety design or operation of such systems for a specific installation. It must be noted that the uncertainty associated with logging of vent releases is judged to be prominent as it is expected that such leaks tend to only be reported if they are detected automatically by exposure to detectors. Furthermore, it may be difficult to filter out such events in the data basis. As operational failures tend to be a dominate cause for vent leak scenarios it is difficult to establish a vent release frequency even if the number of releases should be known due to lack of reliable exposure data, i.e. number of vents and tank operations.

6 References

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/4/ Lloyd's Register Consulting, "Blowout and well release frequencies based on SINTEF offshore blowout database 2014", 17 March 2015, Report No: 19101001-8/2015/R3 Rev: Final

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/8/ DNV, Offshore QRA – Standardised Hydrocarbon Leak Frequencies, report number 2009-1768, rev. 1, Date. 16.01.2009.