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SINTEF Industrial Management
Safety and Reliability

Address: NO-7465 Trondheim, NORWAY
Location: S P Andersens veg 5
Telephone: +47 73 59 27 56
Fax: +47 73 59 28 96

Enterprise No.: NO 948 007 029 MVA

TITLE

Safety barriers to prevent release of hydrocarbons during production of oil and gas

AUTHOR(S)

Snorre Sklet and Stein Hauge

CLIENT(S)

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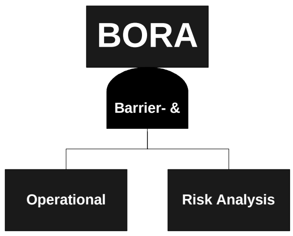
ABSTRACT

This report documents a set of scenarios related to release of hydrocarbons during production on oil and gas platforms. For each release scenario, initiating events, barrier functions aimed to prevent loss of containment, and barrier systems that realize these barrier functions are identified and described.



This report is developed as part of the Barrier- and Operational Risk Analysis (BORA) project.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Safety and security	Sikkerhet
GROUP 2	Safety systems	Sikkerhetssystemer
SELECTED BY AUTHOR	Risk analysis	Risikoanalyse
	Safety barrier	Sikkerhetsbarriere
	Hydrocarbon release	Lekkasje av hydrokarboner

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Executive summary

This report documents an attempt to develop a set of hydrocarbon release scenarios that can constitute the basis for analysis of platform specific frequencies of release of hydrocarbons in future risk analyses. The release scenarios may be used to identify and illustrate barriers aimed to prevent release of hydrocarbons. Further, the release scenarios may constitute the basis for analysis of the effect on the total risk of these barriers, and analysis of the effect of risk reducing measures (or risk increasing changes).

Each release scenario is described in terms of an initiating event (i.e., a “deviation”) reflecting causes of hydrocarbon releases, the barrier functions aimed to prevent the initiating event from developing into a release, and how the barrier functions are implemented in terms of barrier systems.

The release scenarios are divided into seven (7) main groups and some of these groups are divided further into sub-categories:

1. Release during maintenance of HC-system (requiring disassembling)
    a. Release due to failure prior to or during disassembling of HC-system
    b. Release due to break-down of isolation system during maintenance
2. Release due to latent failure introduced during maintenance
    a. Release due to incorrect fitting of flanges or bolts during maintenance
    b. Release due to valve(s) in incorrect position after maintenance
    c. Release due to erroneous choice or installations of sealing device
3. Release due to operational failure during normal production
    a. Release due to maloperation of valve(s) during manual operation
    b. Release due to maloperation of temporary hoses.
    c. Release due to lack of water in water locks in the drain system
4. Release due to technical/physical failures
    a. Release due to degradation of valve sealing
    b. Release due to degradation of flange gasket
    c. Release due to loss of bolt tensioning
    d. Release due to degradation of welded pipes
    e. Release due to internal corrosion
    f. Release due to external corrosion
    g. Release due to erosion
5. Release due to process upsets
    a. Release due to overpressure
    b. Release due to overflow / overfilling
6. Release due to external events
    a. Release due to impact from falling object
    b. Release due to impact from bumping/collision
7. Release due to design related failures

Group 1 – 3 belong to the cause category human or operational failures, group 4 belong to the cause category technical failures, group 5 belong to the cause category process upsets / process parameters out of range, group 6 belongs to the cause category external events, while group 7 include latent failures from design.

The presented scenarios do not cover all possible causes of release of hydrocarbons, but is considered to constitute a comprehensive and representative set of release scenarios. The initiating events cover the most frequent “causes” of hydrocarbon releases, and the scenarios include the most important barrier functions aimed to prevent releases.

It has been attempted to use the safety barrier terminology suggested by a working group within the Together for Safety initiative (/21/). As a result, a distinction between barrier functions and safety barriers has been made in the scenario descriptions. However, in most of the scenarios, it has been assumed that corrective action, or at least risk compensating measures are implemented when deviations are detected. Thus, the barrier elements decision and action are not described in the scenarios.

The set of release scenarios will form the basis for the overall barrier model to be developed in the BORA project. This model will “link” the release scenarios with the barrier function(s) aimed to limit the consequences; i.e., prevent ignition, reduce release, prevent escalation, and prevent fatalities. Further work will also be carried out in the BORA project in order to develop a framework for analysis of risk influencing factors and quantification of the scenarios.

1. Introduction

1.1 Background

This report is developed by SINTEF as a part of the H1-activity in the Barrier and Operational Risk Analysis (BORA) project (/1/, /2/). The project is part of the research programme “Health, Environment, and Safety in the Petroleum Industry”, financed by The Research Council of Norway (NFR). In addition, The Health and Safety Executive (HSE) in UK and The Norwegian Oil Industry Association (OLF) are sponsors of the project. The overall project coordinator is Jan Erik Vinnem, HiS/Preventor.

The main purpose of the BORA project is to conduct a case study where analysis of barriers on offshore production installations is carried out, both for physical and non-physical barriers. Barriers intended to prevent the incident occurring along with those intended to eliminate/reduce consequences are included. Particular emphasis is placed on the operational phase of the total life-cycle and barriers aimed to prevent accidents during execution of operational activities.

1.2 Purpose and scope of the report

The focus of this report is modelling of the containment barrier on oil and gas production platforms, which has been done by presenting a comprehensive set of hydrocarbon release scenarios. The release scenario models cover both initiating events, barrier functions aimed to prevent releases, and barrier systems that realize these barrier functions.

The set of release scenarios will form the basis for the overall barrier model to be developed in the BORA project. This model will “link” the release scenarios with the “consequence barriers” by using the RiskSpectrum program. Hence, connection and dependencies between each release scenario (in terms of cause, operational phase at time of release, etc.) and the status of the consequence barriers will be reflected in this model.

1.3 Constraints and limitations

A main purpose of the BORA project is to address the barrier situation in detail during different operational activities and phases, but the scope is limited to releases in the process area on a platform. This means that for example releases during well-operations are not included as a release scenario.

This report only deals with the containment barrier. Other barrier functions (prevent ignition, reduce release, prevent escalation, and prevent fatalities) are described in other memos from the project. The purpose is to develop a representative and comprehensive set of release scenarios in order to cover the most important types of initiating events and barrier functions aimed to prevent releases of hydrocarbons. This implies that some events or conditions that might lead to leaks will not be covered. However, the most significant contributors towards loss of containment should be included.

The Brage platform was chosen as a case for the BORA-project, however, documentation from other platforms has also been utilised as basis for the report. Hence, the models in this memo are by nature general.

Quantification has not been the objective of this project phase. Nevertheless, the possibility of quantification has been reflected in the work because quantification is a declared objective of the next phase in the project.

In most of the Barrier block diagrams presented in chapter 9, we assume that corrective actions, or at least risk compensating measures are implemented when deviations are detected. The validity of this assumption will be further discussed as part of the quantification process.

1.4 List of abbreviations

BBD	Barrier Block Diagram
BORA	Barrier and Operational Risk Analysis
CM	Corrective Maintenance
ESS	Emergency Support System
HIPPS	High Integrity Pressure Protection
HSE	Health and Safety Executive (UK)
HRA	Human Reliability Assessment
IE	Initiating Event
IEC	International Electrotechnical Commission
LoC	Loss of Containment
LSH	Level Safety High
MTO	Man, Technology and Organisation
NDT	Non Destructive Testing
NPD	Norwegian Petroleum Directorate (OD)
PM	Preventive Maintenance
PSD	Process Shutdown
PSH	Pressure Sensor High
PSV	Pressure Safety Valve
QRA	Quantitative Risk Analysis
RNNS	Risk level on the Norwegian continental shelf (Risikonivå på norsk sokkel)
SOP	Standard Operational Procedures
WO	Work Order
WP	Work Permit

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2. Principles for description of release scenarios

2.1 Scenario description

A release scenario is composed of an initiating event, barrier functions aimed to influence the event sequence, in this case to *prevent release of hydrocarbons*, and the realization of the barrier functions in terms of barrier systems. Based on previous decisions in the project group, barrier block diagrams (corresponding to event trees) are used to describe the release scenarios, i.e., to model the events prior to the release and to visualise the *barrier functions and barrier systems/elements available to prevent the leak.*

It has been attempted to apply the terminology on safety barriers suggested by a working group within the Together for Safety initiative (/21/). The working group defines the following terms: [1]

- Barrier function
- Barrier system/-elements
- Performance influencing factors

Further, each release scenario is described in a table where the following information is included:

- Scenario name
- General description
- Initiating event
- Factors influencing the initiating event
- Operational mode when failure is introduced
- Operational mode at time of release
- Barrier functions
- Barrier systems/elements
- Assumptions

The event sequence is visualised in a *barrier block diagram* as illustrated in Figure 1. A barrier block diagram consists of an initiating event, arrows that show the event sequence, barrier functions realized by barrier systems, and possible outcomes. An arrow straight on indicate that a barrier system functions (i.e., fulfil its function), whereas an arrow downwards indicate failure to fulfil the barrier function. In our case, the undesirable event is release of hydrocarbons (loss of containment).

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[1] Suggested terms in /21/.

Concept	**Definition/description**	**Performance (goodness)**
Barrier function (BF)	Function to prevent the realization of a hazardous situation or threat, or reduce the damage potential. May be divided into barrier subfunctions.	Normally given by probability of satisfying the function.
Barrier system/-elements (BS)	MTO-solutions that give the desired function. May be divided into barrier elements.	Given by e.g., reliability, efficiency, robustness.
Performance influencing factors	Factors that influence the performance (goodness) of BFs and BSs. Maintenance, resources, competence, etc.	

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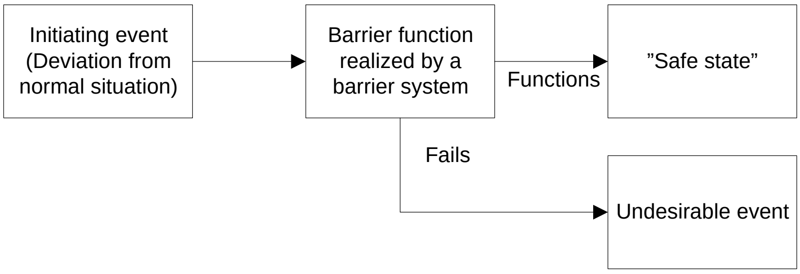

Figure 1. Illustration of a barrier block diagram.

One main purpose of a barrier block diagram is to illustrate available barrier functions intended to prevent a deviation (i.e. an initiating event) from escalating into a release, and how these functions are realized by barrier systems. In quantitative analyses, the event sequence will be represented by an event tree, and each barrier can be analysed in detail by use of fault trees, influence diagrams, human reliability analysis, event/failure data, expert judgements an/or other suitable methods, in order to estimate the probability of failure of a barrier. Incident/accident data, other relevant data, expert judgements or fault tree analysis can be used to estimate the frequencies of the initiating events.

If it is found practical to analyse a given barrier function by the use of a fault tree, then fault trees and event trees may be combined in one common model by the use of RiskSpectrum.

A barrier block diagram may include more than one barrier function prior to the actual loss of containment. Further, more than one barrier system may be implemented in order to realise a barrier function and all the barrier systems will be illustrated in the barrier block diagrams. For the case “Release due to incorrect fitting of flanges or bolts during maintenance”, the diagram in Figure 2 can illustrate this point. Here, it is indicated that the initiating event and each barrier system is analysed by using a fault tree, but as discussed above, other approaches may also apply.

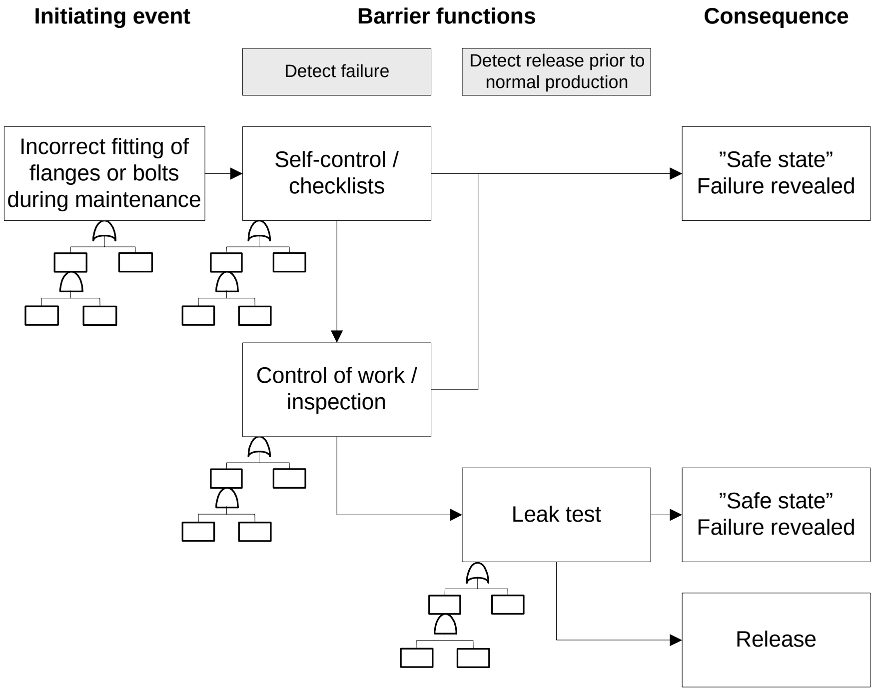

Figure 2 Barrier block diagram –‘incorrectly fitted equipment’

In principle, each active barrier system should include the three subfunctions detection, decision, and action in order to fulfil a barrier function. However, this principle is not complied with in the scenario descriptions, but will be allowed for in the future work regarding quantification.

2.2 Main rule for identification of initiating events:

The following definition is used in order to identify initiating events for the release scenarios:

> *Initiating events for the release scenarios are defined as the first significant deviation from normal situation that under given circumstances may cause release of hydrocarbons (loss of containment).*
>
> *A "normal situation" is a state where the process functions as normal according to design specifications without considerable process upsets or direct interventions in the processing plant.*

Regarding operational failures, it is crucial to explicitly define the initiating events in such a way that it is evident what the deviation from the normal situation is. In addition, the time aspect and the personnel involved should be stated, e.g.:

- Failure during maintenance (e.g., incorrect assembling of a gasket/seal during maintenance of a flange) that may lead to hydrocarbon leakage during start-up or later during normal production.
- Failure to isolate, depressurise, drain, or purge a segment of the processing plant before disassembling of a valve in the segment. The release occurs while disassembling the segment.

Another important point to keep in mind is that the initiating event should be defined in a manner so that quantification is possible.

The definition of a hydrocarbon release used in this project is influenced by the purpose of the BORA project and is based on a risk analysis approach. Usually, the consequences of hydrocarbon releases larger than 0,1 kg/s are modelled in quantitative risk analysis. This criterion is also chosen in the BORA-project. Hydrocarbon releases less than 0,1 kg/s are regarded as minor releases and will not be further modelled in the BORA project.

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3. Research approach for development of release scenarios

The process for development of release scenarios has included several steps as shown in the flowchart in Figure 3.

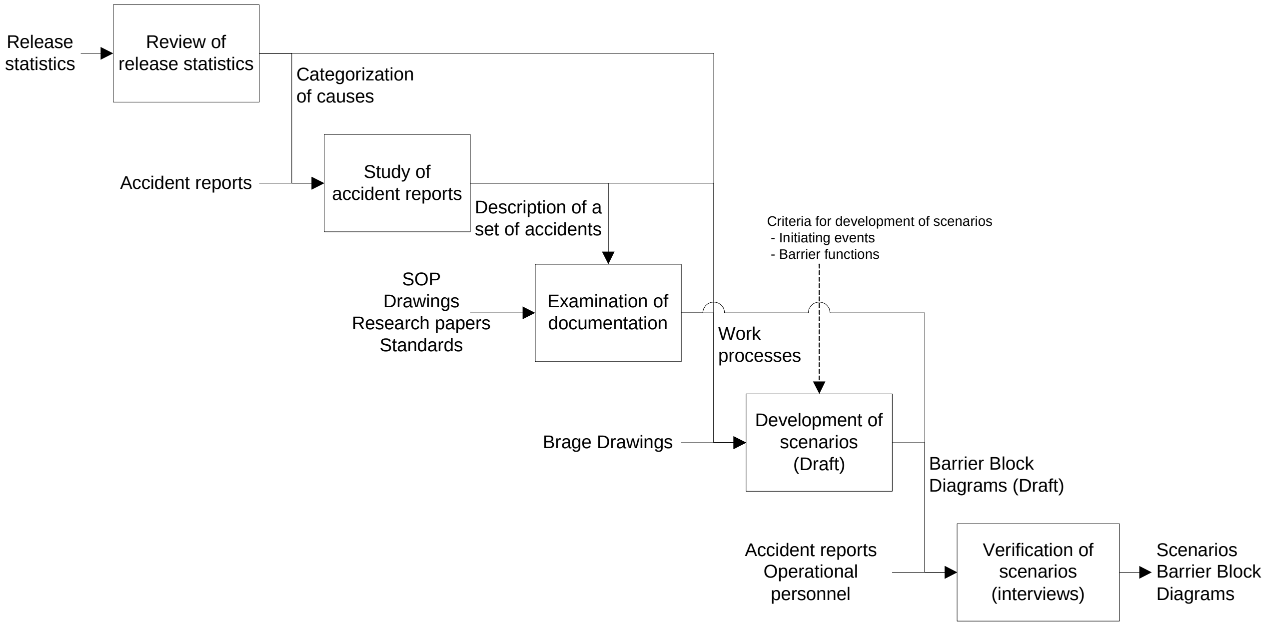

Figure 3. Flowchart for development of release scenarios.

A review of release statistics from HSE covering the British sector in the North Sea (/4/, /5/), data from the NPD covering the Norwegian Continental Shelf (/6/) and reports from some other studies of hydrocarbon releases (/8/, /9/, /10/) has been performed.

The purpose of the review was to identify causes of the releases in order to develop a coarse classification of releases. Based on this review of release statistics, a generic top level fault tree was developed that shows an overall categorization of causes of hydrocarbon releases. This fault tree is described in section 4.2.

Further, a detailed study of accident investigation reports from 40 hydrocarbon releases was performed. The sample of accidents was medium or large hydrocarbon releases from the last three years from two Norwegian oil companies. In addition, Synergi reports of several small hydrocarbon releases from the case-platform and other installations were studied.

The purpose of the study of releases was to get a more thorough understanding of multiple causal relationships leading to the releases, both regarding initiating events (deviations) and failed or missing barrier functions. The study resulted in a list including short descriptions of the releases, see Chapter 5.

An examination of some additional documentation was also performed. The purpose of this work was to get an insight into which technical systems and work processes that may influence the leak probability, and to identify requirements and functions related to these systems.

The following types of documentation were examined:

- Operating procedures (SOP) and drawings from Brage (/13/, /16/, /20/)

- Standards (/14/, /15/)
- Research papers (/18/, /19/, /23/, /24/)

The examination resulted in knowledge about the technical systems and how different work processes should be performed. Some results from this work are presented in Chapter 6.

The next activity was the definition of release scenarios. The purpose of this activity was to develop a set of release scenarios that should fulfil the following criteria:

1. The release scenarios should reflect possible causes of hydrocarbon releases.
2. The release scenarios should include important barrier functions that influence the probability of leaks.
3. The release scenarios should to the extent possible be suitable for quantification (both as regards to the frequency of initiating events and the probability of failure of barrier functions).
4. The release scenarios should reflect different activities, phases and conditions.
5. The release scenarios should provide a basis for and facilitate installation specific considerations to be performed in a “simple” and not too time-consuming manner.
6. The release scenarios should form a representative and comprehensive sample of events and conditions that might lead to release of hydrocarbons.

Based on the results from all the activities described above, the project group at SINTEF developed the first version of the release scenarios (draft release scenarios).

A thorough process for assessment of the draft scenarios was further performed. The main steps of this validation/verification process were:

1. Comparison with the master logic diagram for “Loss of containment” in chemical plants developed in the I-RISK project (/19/).
2. Comparison with hydrocarbon release incidents (/11/, /12/).
3. The draft release scenarios were submitted for review by personnel from Hydro and the whole project group, and the scenarios were discussed in a meeting where personnel from Hydro and the project group attended.

A detailed description of the final release scenarios is given in chapter 9.

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4. Review of release statistics

Release statistics from HSE covering the British sector in the North Sea, data from the NPD covering the Norwegian Continental Shelf and reports from some other studies of hydrocarbon releases (/8/, /9/, /10/) was reviewed.

The purpose of the review was to identify release causes in order to develop a classification scheme suitable for further modelling of the loss of containment barrier. Also, in order to get an overall impression of the main contributors towards hydrocarbon leaks, such a review was necessary.

4.1 Release statistics

HSE has published release statistics for the period 01-10-92 to 31-01-02 (/4/). The statistics include data from 2312 reported releases[2]. Figure 4 shows the distribution of direct causes of these leaks.

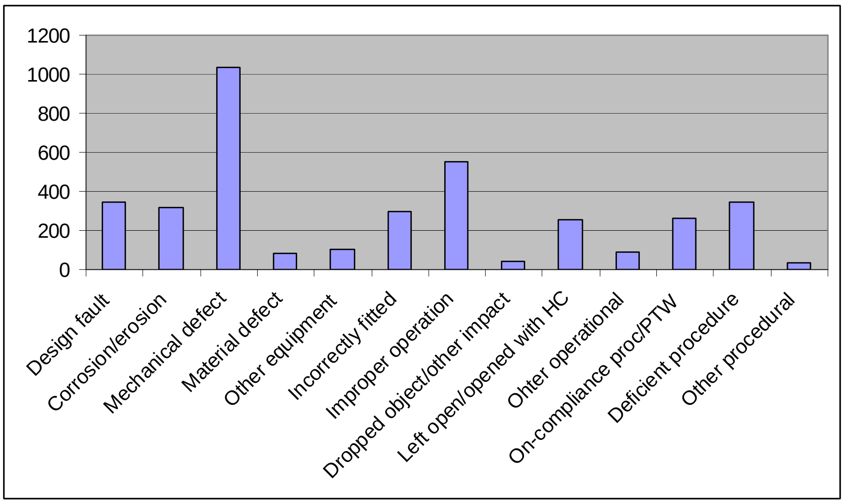

Figure 4. Direct causes of hydrocarbon releases based on /4/.[3]

Figure 5 shows the location of releases according to the data from HSE for the 241 releases in 2001/02. Pipework (including pipe flange, weld, body and open end, small bore piping and connections, and instrument connections) accounts for the majority of leakages (62 %). Valves were involved in 21 % of the releases, vessels 6 %, and pumps 6 %.

Figure 6 shows the location of the releases in the full set of HCR data and shows that releases from instrument (22 %) and pipework (22 %) dominate. In a study by Norsk Hydro of all HC releases reported in Synergi between 01.07.1992 and 31.12.2000 (/9/), leaks from valves were dominating (see Figure 7).

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[2] By which 11,6 % are due to non-process leaks (diesel, helifuel, lubricants, methanol, etc.

[3] More than one cause might be registered for each release (3747 causal factors for totally 2312 releases).

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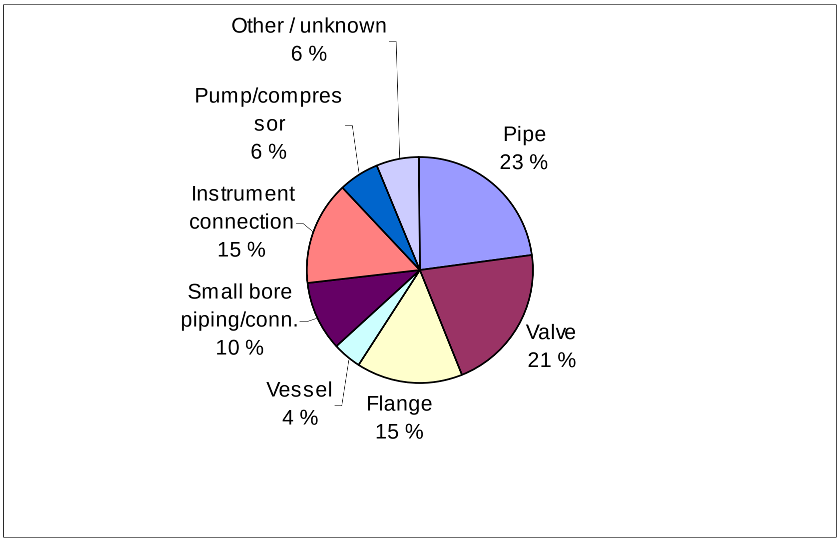

Figure 5. Release source in the data from HSE (/4/).

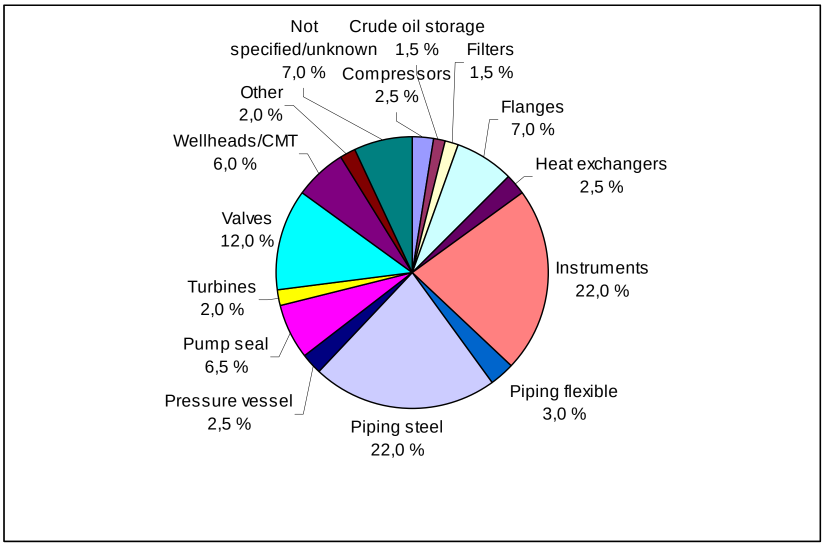

Figure 6. Location from the HCR Database (/4/).

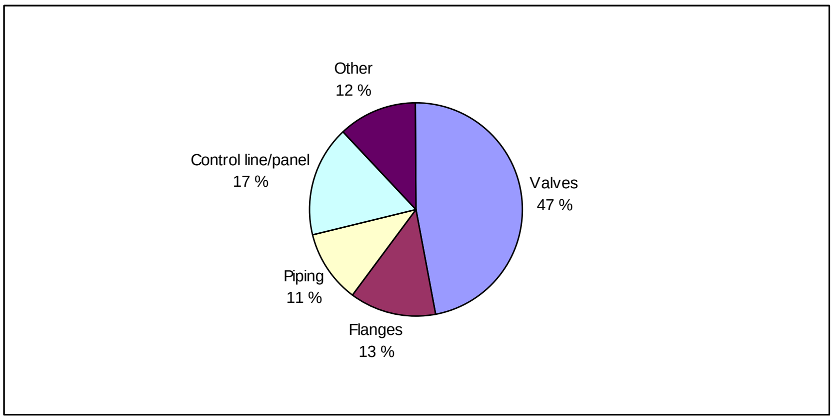

Figure 7. Component where leak occur in Norsk Hydro (/9/).

The NPD had published data from the project “The Risk Level on the Norwegian Continental Shelf” (The RNNS-project). These data include 68 releases in the period from 1.1.2001 to

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30.6.2003. In this period a total of 73 leakages are reported, but the causes are known only for 68. The data from the Norwegian sector include one cause for each release, while the British data may include multiple causes. A comparison of the release causes is shown in Figure 8.

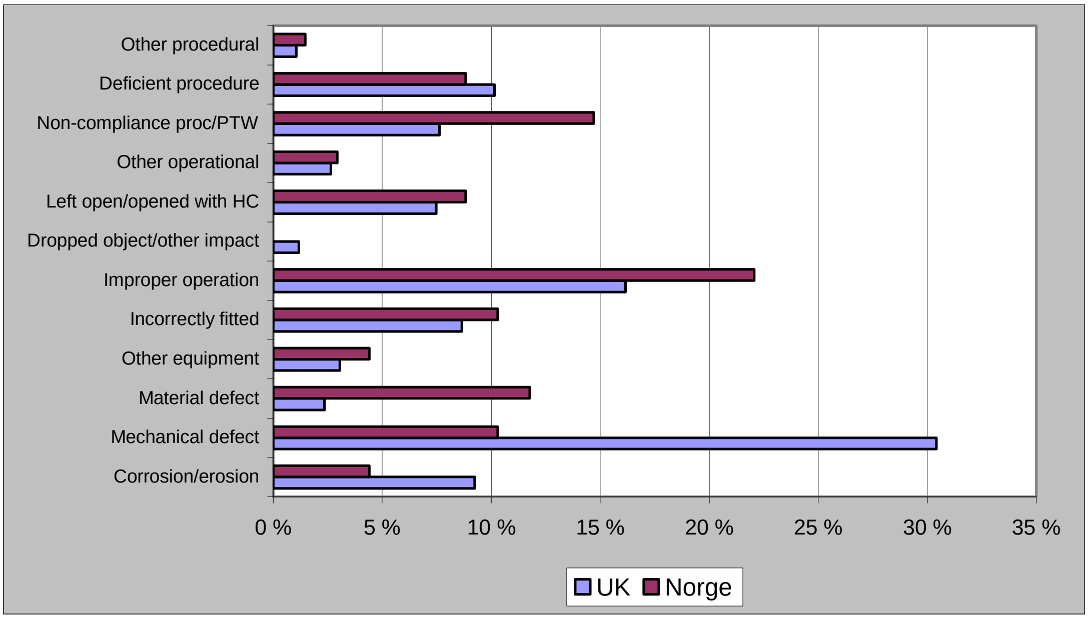

Figure 8. Comparison of release causes in the British and Norwegian data (/7/).

Figure 9 shows the distribution of operation modes at the time of release for the Norwegian data, while Figure 10 shows the equivalent data from HSE. As seen from these figures, the NPD and HSE use different categorizations, so the data are not directly comparable, but the data from HSE indicate that almost 50 % of the releases occur during normal production, while the data from the Norwegian sector indicate that this part is less. In a Norsk Hydro internal study (/8/), 69 % of the releases occurred during normal production.

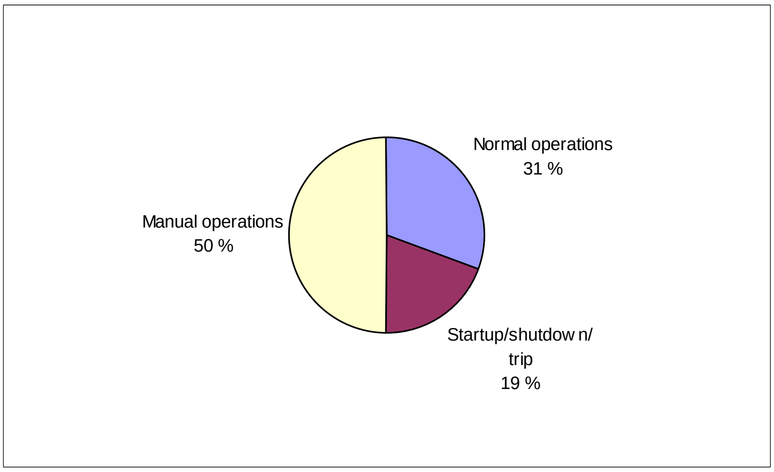

Figure 9. Operation mode at the time of release - Norwegian data.

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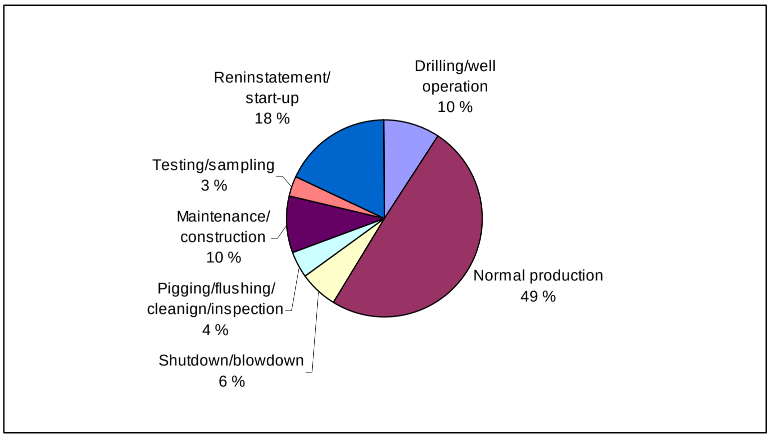

Figure 10. Operation mode at the time of release - British data.

Some conclusions can be drawn based on the statistics:

- Operational errors such as improper operation, incorrectly fitted equipment and procedural deficiencies are major contributors towards leaks on the Norwegian sector.
- These “operationally caused leaks” normally occur during maintenance, testing or during start-up after a shutdown;
- For the UK leaks, the dominating causal contributor is mechanical defect, while this part is smaller in Norway.
- The technically caused leaks often occur during normal production.
- With respect to areas on the installation, compression and wellhead are the two areas with the most leaks (high pressures and many leak points);
- Pipework (incl. instrument connections), valves and flanges are the dominating types of equipment where leaks occur.

It should be pointed out that for large releases, operational errors tend to have a relatively greater importance, i.e. accounting for a larger proportion of the leaks. This reflects the increased role of operational errors in the larger releases, as opposed to hardware and/or equipment failures, ref. (/5/).

4.2 Classification of release causes

Based on the release statistics, a classification of the releases as shown in the fault tree in Figure 11 was developed. In the fault tree, the top event “Release/loss of containment” has been broken down to a level that shows more specific causes of potential releases. Based on this fault tree, possible release scenarios will be developed (see chapter 9).

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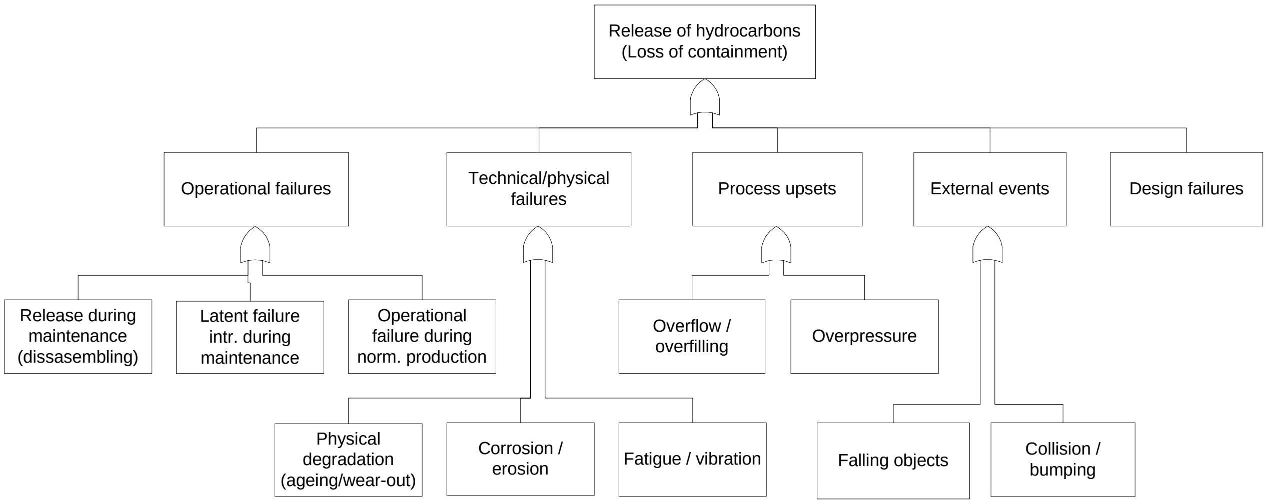

Figure 11. Fault tree for the top event "Release of hydrocarbons" (Loss of containment).

As the figure shows, the release causes are divided into five main "groups" of failures:

1. Operational failures
2. Technical failures (physical degradation/equipment failures)
3. Process upsets (process parameters out of range)
4. External events/loads
5. Design failures

Operational failures typically include releases due to failures during isolation, depressurization, draining, blinding, and purging prior to maintenance activities, failures introduced during maintenance (e.g., inadequate assembling and installation of equipment), and operational failures during normal production like valves left in open position after taking of samples, open valves to the drain-system, etc.

Technical or physical failures typically include releases due to mechanical and material degradation of equipment, corrosion, erosion and fatigue/vibration.

Process upsets typically include releases due to overpressure, underpressure, overflow, etc.

External events/loads typically include releases due to falling objects, collisions, bumping, etc.

Design related failures are latent failures introduced during design that cause release during production.

The fault tree shown in Figure 11 does not treat multiple causes of releases. This topic is, however, treated by further development of release scenarios described in chapter 9.

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5. Study of hydrocarbon release incident reports

In order to develop a representative and comprehensive set of release scenarios, accidents reports from 40 hydrocarbon releases were studied in detail (/11/, /12/). These accident reports serve as input both to define initiating events, barrier functions, and barrier systems.

A short description of the releases (in Norwegian) is given in Table 1.

The classification of each release scenario according to the different accident reports is documented in Table 2 in section 8.2. It may be mentioned that this was an iterative process. As the release scenarios was developed and changed, the classification was changed. Table 2 documents the final classification.

Table 1. Short description of hydrocarbon releases (in Norwegian).

Nr	Beskrivelse	Direkte årsak	Scen no.	Operasjons-modus	Deteksjon	Barriere-/sikker-hetsfunksjoner
1	Gasslekkasje CD2 oljemålestasjon	Utvendig korrosjon. Rør ikke underlagt inspeksjonsprogram	4f	Normal drift (Inspeksjon)	Automatisk GD001 100% LEL	??
2	Utilsiktet utslipp av gass ved utsjekk av dobbel B & B	Lekkasje gjennom bleed (til friluft i stedet for slange til CD). Mangelfull drenering. Internlekkasje XV-ventiler. Drain-ventiler blokkert pga hydrat-dannelse.	1a	Inspeksjon/ Vedlikehold	Automatisk	NAS 2 Autom. nedst. Autom. tennk.utk.
3	Brenngass ut av vent/NAS 2	3-veis ventil i feil posisjon ved oppstart av kompressor. Brenngass blåste ut av vent. Logikk muliggjør feilsetting av ventiler.	2b	Oppstart (av eksp. komp.)	Automatisk 46 % LEL 2 linjedet.	NAS 2 Autom. nedst.
4	Gassutslipp fra avlufting/ miniflow på vanninjeksjon	Ved trip av vanninj.pumpe ble det fortsatt pumpet slop inn i vanninj. pumpe. "Miniflow"-ventil åpnet (sikkerhetsfunksjon) og pumpet slop rett over bord.	5b	Normal drift	Automatisk 2 linjedet.	NAS 2 Autom. nedst. Autom. tennk.utk.
5	Gasslekkasje pga feil montering av transmitterhus	4 bolter manglet i instrumentblokk. Mangelfull kvalitetsskontroll/ verifikasjon av utført arbeid.	2a	Oppstart	Automatisk 1 detektor 30 % LEL	Man. nedst. Man. trykkavlast. Man. tennk.utk. Generell alarm Evakuering til VFB
6	P/V breaker	Under omlegging av nøytralgassgen- fra atm. til dekk blåste P/V breaker (væskelås) ut (overtrykkssikring av lagertank).	5a	Normal drift	Automatisk Flere linjedet.	NAS 2 Autom. nedst.
7	Lekkasje pga stengte feil ventil ut av PSV	Overhaling av PSV. Innløpsventil ble stengt, feil ventil ble stengt på utløpssiden s.a. denne sto åpen. Ved prod.tripp og trykkavlasting strømmet gass ut av ventilhus Luft ble også dradd inn i fakkelsystemet	1a	Vedlikehold		
8	Gasslekkasje gjennom eksosrør pilot 26 PSV 6101	26PSV6101 var åpnet til fakkel. Det blåste gass ut til atmosfære fra eksosrør fra pilot. Lekkasje over O-ring i pilotventil.	4a	Normal drift/ Oppkjøring	Automatisk 2 det.	NAS 2
9	Gasslekkasje i analysatorskap i M24 M	Pakning i instrumentflens blåste ut. Bolter feilmontert og ikke låst. Mangelfull KS/prosedyrer av utført arbeid. Feil introdusert ifm vedlikehold med lekkasje inntreffer under normal drift.	2a	Normal drift	Automatisk	NAS 2 Trykkavlasting Tennkildeutkobling Deluge Mønstringsalarm

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Nr	Beskrivelse	Direkte årsak	Scen no.	Operasjons-modus	Deteksjon	Barriere-/sikker-hetsfunksjoner
10	Gasslekkasje fra transmitter på gassmålepakke	Pakning på transmitter blåste ut. Skjevt tiltrukket ved en tidl. anledning	2a	Normal drift	Automatisk	NAS 2
11	Lekkasje i flens til måleblende	Flens tiltrukket med for lavt moment. Mangelfull kontroll av utstyr.	2a	Ned-stengning / Normal drift	Automatisk 100% LEL 3 detektorer	NAS 2 Aut. nedstengning Aut. trykkavlasting Aut. tennk.utkobling Mønstringsalarm
12	Gasslekkasje blåst stempakning på ¾ " ventil	Lekkasje fra pakkboks til en ¾" BGA ventil. Stempakning av grafitt-typen og var trolig uttørket/hard og hadde mistet elastisitet/ tettevne. Manglende FV? Gasstrykk i lekkasjeøyeblikk var 300 bar	4a	Brønn-operasjon	Automatisk 3 IR-detekt.	
13	Gasslekkasje på strømningsrør A-13	Lekkasje i "Grey lock" kobling mellom vingventil og strupeventil. Feil pakning har ført til korrosjon? (C-stål pakningsring i et rustfritt system)	2c	Nedstengning av brønn	Automatisk	NAS 2 Autom. deluge
14	Gasslekkasje pga ventslange som ble utilsiktet trykksatt hoppet av kobling.	Utilsiktet trykksetting av ventslange. To åpne blokkventiler skulle vært stengt.	2b	Oppkjøring etter vedlikehold (FV på brønn A20)	Automatisk 30 detekt.	NAS på SLA PAS på SLP DHSV ??
15	Lekkasje ifm avblødning av testtrykk fra brønn	Ifm avblødning ble linje til PoorBoy Degasser og linje til Closed Drain åpnet samtidig. Medførte gassboble gjennom Degassersystem. Ventil feiloperert pga svikt i kommunikasjon	3a	Boring	Automatisk	??
16	Gasslekkasje på rør	Gasslekkasje på rørsveis i endelokk på kompressor. Sprekk pga vibrasjon?	4d	Normal drift	Automatisk 20 % LEL	
17	Utslipp av olje/meg/vann fra drain tank	Lekkasje ifm trykkavlasting/avbløing av trykk til Closed Drain tank. Ventrør for liten dimensjon for avblødd gassmengde. Væske i tank presses via overløp til sjø sammen med gass.	5b	Nedstengning	Automatisk 3 detektorer 18 % LEL	Manuell NAS 2 Mønstring
18	Lekkasje i 2" benn til nivåglass, oljeside CD 2002	Lekkasje i nedre innløpsbenn til LG 2005 pga korrosjon. CO_2 korrosjon på karbonstål. Dårlig utskifting av korrosjonsinhibitor i denne delen av systemet.	4e	Normal drift	Automatisk	Manuell NAS 2 Man. trykkavlasting Aut. tennk.utkobling Man tennk.utkobling Man. skumlegging
19	Gasslekkasje pakkboks på ¾ " manuell ventil på equalizingsystem	Utett ventilpakkboks. Grafittlignende pakningsmateriale svært "hardt". Manglende FV	4a	Brønnvedlikehold (WL) Oppstart	Automatisk 39 % LEL Linjedet.	
20	Gasslekkasje brønn C-16	Stemlekkasje på vingventil. Endring av service/designbetingelser for brønn.	4a	Oppstart av brønn	Automatisk IR pkt.det.	NAS 2 NAS 1 (M16) Aut. trykkavlasting Aut. tennk.utkobling DHSV
21	Liten gasslekkasje fra målestasjon for løftegass	Etter FV på målepakke for gassløft ble 2 ventiler stående i åpen posisjon. Manglende kontroll av utført arbeid.	2b	Oppstart	Automatisk 30 % LELL	NAS 2 Deluge Alarm Mønstring

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Nr	Beskrivelse	Direkte årsak	Scen no.	Operasjons-modus	Deteksjon	Barriere-/sikker-hetsfunksjoner
22	Liten lekkasje ved demontering av ventil	Rør ikke fullstendig tømt for gass under gassfriingsoperasjon	1a	Vedlikehold	Automatisk 29,3% LEL	
23	Gasslekkasje fra bleed port 26. PIT 026	Manglende tilbakestilling av ventil (åpen bleed). Manglende KS/verifikasjon av utført arbeid.	2b	Oppstart etter vedlikehold	Automatisk 10 % LEL	Aut. tennk.utkobling
24	Gasslekkasje ifm bytte av brennstoff i generator	Ventil i feil posisjon (solenoid ventil ikke stengt) som førte til gass i vannutskillerne.	3a	Testing	Automatisk	Aut. tennk.utkobling
25	Utilsiktet gass i vent post	Quick close valve stengte ikke 100 % og da ble gass kjørt i fuelgass ventpost Saltbelegg på ventil-spindel årsak til at den ikke lukket 100 %.	??	Normal drift		
26	Stor gasslekkasje i pilot til 26PSV6055.	Materialfeil på filter	??	Normal drift	Automatisk	Man. nedstengning Man. trykkavlasting
27	Oljelekkasje i M11	Under avisolering av instrumentrør på oljemålestasjon i M11 løsnet et 10 mm oljeførende rør i koblingen. Sannsynlig årsak mangelfull tiltrekking av fittings på instrumentsrør	2a	Vedlikehold	Manuell	NAS 2 Alarm Mønstring
28	Gasslekkasje fra carcass A-07	Lekkasje i åpent drenshull i flens på "hang-off" riser til brønn A-07. Lekkasje i stigerør.	--	Vedlikehold/ modifikasjon	Automatisk 1 detektor > 20% LEL	
29	Gasslekkasje ved stengning av ventil WB-23-0132	Stempakning på ventil blåst ut under ventiloperering. Pakning henger seg fast i ventilspindel pga manglende smøring. Mangelfull FV for smøring av ventilspindler.	4a	Normal drift ??	Automatisk 2 detektorer	NAS 2
30	Gasslekkasje ifm kalibrering av transmitter	Transmitter isolert med kun en ventil. Lekkasje ifm frigjøring av avblødningslinje for påkobling av kalibreringsinstrument. Kobling opp mot trykktransmitter ikke fagmessig utført.	2a	Normal drift (krever ikke sikkerhets-klaring)	Automatisk mange det > 60% LEL	ESD II Blowdown
31	Gasslekkasje i WAG-modul P56	Gass fra fakkelsystem til friluft ifm trykkavlasting av Vigdis kompressor. Manglende blinding etter fjerning av WAG-kompressor. Utblinding av kompressor utført etter gjeldende prosedyrer men tegnings-underlag var feil (ikke oppdatert P&ID).	1a	Vedlikehold / Utfall av kompressor	Manuell + automatisk	PAS 3.1 NAS 2 Nødkraft Generell alarm Mønstring
32	Gasslekkasje i instrument-tubing tilknyttet 27 PT 0196	Transmitter 27PT0196 sto skjevt på resten av tubing og gass lekket ut fra brudd i tubing. Årsak er vibrasjon, manglende supportering og uheldig design.	4d	Normal drift	Manuelt	Avstengning av ventiler
33	Gasslekkasje i body PZV på riser EV 13 0071 A08	Ved operasjoner, åpne og stenge, på EV-13-0071 blåste 540 bars sikkerhetsventil i ventilbody. Årsak ikke beskrevet.	??	?? Normal drift	Manuell (gass-sky så tett at man ikke så gjennom)	Avstengning av ventiler
34	Gasslekkasje fra ventil	Lekkasje i pakkboks på ventil WL-16-0062 på overgang (cross-over) fra gassutjevning til oljeutjevning i C51. Skjevt tiltrukket pakkboks s.a. grafittpakning ble blåst ut	2a	Oppstart etter revisjons-stans	Automatisk	NAS 2 Generell alarm Mønstring

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Nr	Beskrivelse	Direkte årsak	Scen no.	Operasjons-modus	Deteksjon	Barriere-/sikker-hetsfunksjoner
35	Gasslekkasje fra ventlinje for produsert vann til sjø	Høyt HC-innhold i produsert vann til sjø førte til at det kom gass ut av vent for dumpelinje til sjø. Forurensinger i testseparator medførte at nivåregulering i testseparator feilet. Testsep. burde vært stengt ned.	5b	Normal drift	Automatisk 3 detektorer >100% LELL	NAS 2 Generell alarm Mønstring
36	Gasslekkasje i TZV i ventilhus NP 23-060 oppstrøms PZV 231221 A	TZV i ventilhus NP 23-060 oppstrøms PZV 231221 A hadde åpnet til atmosfæren. (sikkerhetsventil på kuleventil). Uheldig design. Ventil åpnet på 50 bar i stedet for 465 bar. Mangelfull FV / kalibrering	7	Normal drift	Manuell	Manuell PAS 4.23.2 Trykkavlasting Generell alarm Mønstring
37	Gasslekkasje fra oljevarmer i modul 04	Lekkasje gjennom åpen avluftingsventil og åpen brilleflens i dreneringslinje fra varmemedium siden. Ventil i feil posisjon. Blindingsliste avviker fra blindingsplan.	1a	Vedlikehold	Automatisk 2 detektorer > 20% LEL	NAS 2 Alarm Mønstring
38	Gasslekkasje fra kondensat-eksporttank	Gassgjennomstrømning fra kondensat-eksporttank til drenssjakt. Væskelås fra TA401 mot sump-caisson tørr i etterkant av hendelse. Gass-blowby pga lavt væskenivå grunnet avgassing.	3c	Oppstart	Automatisk 2 detektorer > 20% LELL	NAS 1 Autom. tennk.utk. Aut. brannp.start Beredskapsorg. mønstret
39	HC-lekkasje i flens mot ventil	Flens ikke tiltrukket med riktig moment. Nyinstallert linje grovlekkasjetestet med N2 til 8 bar, men videre opptrykking med HC til fullt operasjonstrykk ikke gjennomført. Mangelfull overtakelse av modifikasjonsprosjekt.	2a	Oppstart av brønner	Automatisk 6 detektorer	NAS 2 Generell alarm Mønstring
40	Gasslekkasje i nivåglass i M04	Pakning i nivåglass sviktet. Feil materialkvalitet på pakning	2c	Oppstart etter FV	Automatisk	Aut. deluge Aut. nedstengning Aut. trykkavlasting Alarm Mønstring i livbåt

6. Review of documentation and literature

A review of some additional documentation has also been performed. The purpose of this work was to get an insight into which technical systems and work processes that influence the leak probability, both regarding the frequency of initiating events, barrier functions aimed to prevent deviations from developing further into release of hydrocarbons, and how barrier system are implemented in order to realize these barrier functions.

The following types of documentation were examined:

- Operating procedures (SOP), work descriptions, maintenance strategy document, and drawings from Brage (/13/, /16/, /20/)
- International standards (/14/, /15/)
- Research papers (/18/, /19/, /23/, /24/)

The review of operational procedures (/16/) led to an understanding of various work processes. As an example, a specific description of the work process "Work on HC-system" is presented in the operational sequence diagram shown in Figure 12.

Another procedure reviewed was the OLF Recommended Guidelines for Common model for Work Permits (WP) (/20/). Figure 13 shows the main steps in the work permit process.

Figure 14 shows a conceptual framework for causes of events (/17/ (adapted from /18/)). This framework includes a list of front-line programs obviously influencing the leak probability (either the frequency of initiating events or the performance of barrier functions):

- Maintenance
- Inspection/testing/calibration
- Operations/controls
- Design
- Installation

These front-line programs are taken into consideration while developing the release scenarios described in chapter 9.

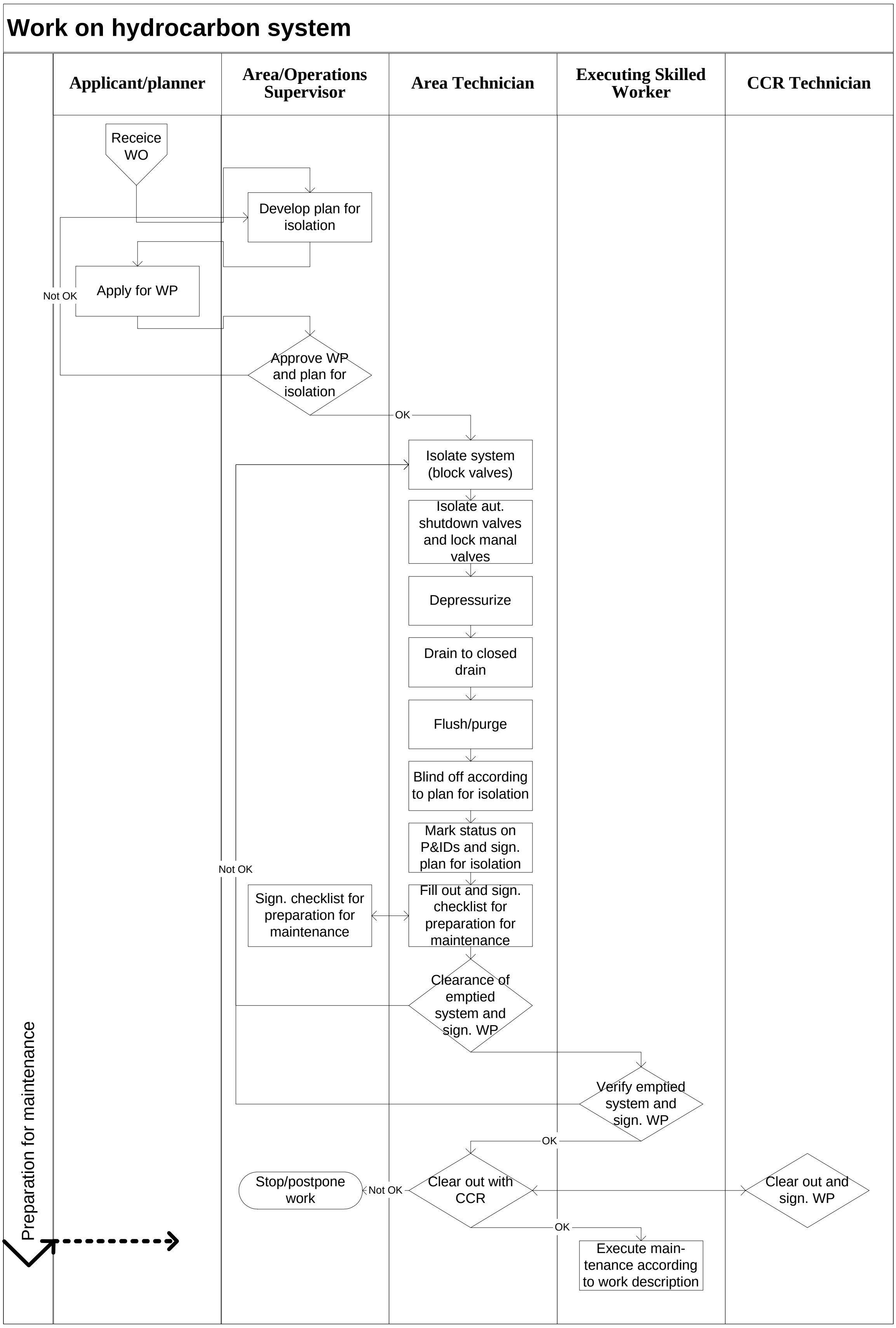

Figure 12. Description of the work process “Work on hydrocarbon system”.

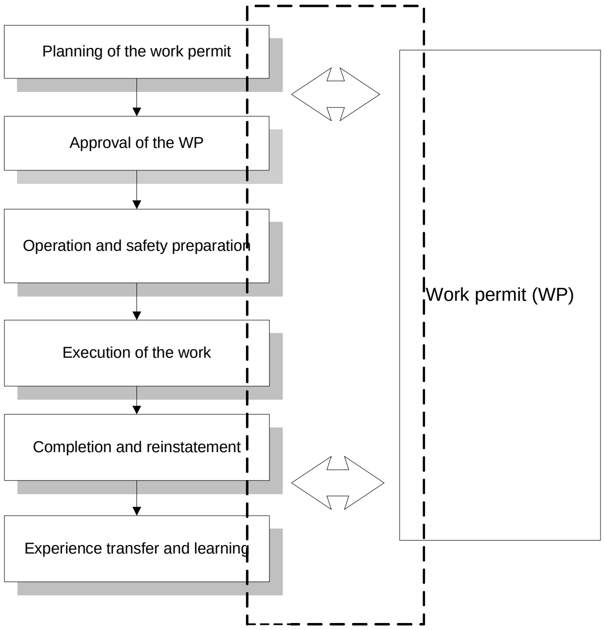

Figure 13. Main steps in the work permit process (/20/).

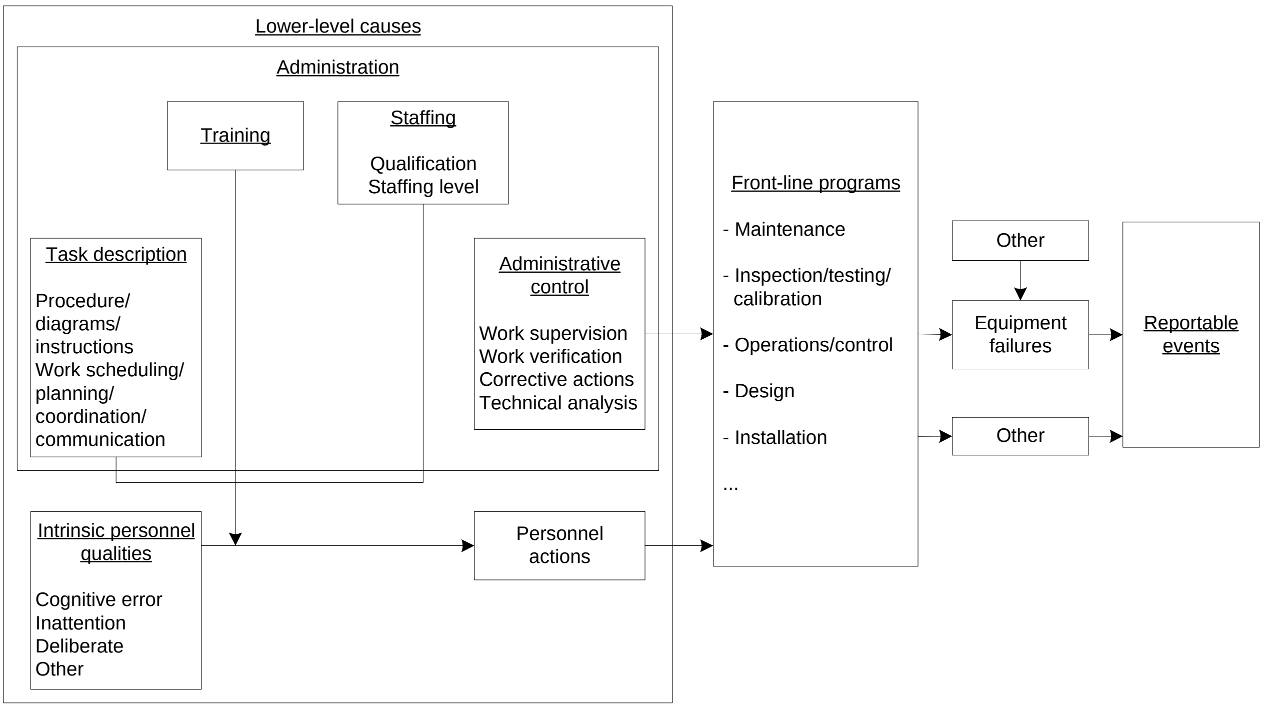

Figure 14. Conceptual framework for the causes of events (/17/ (adapted from /18/)).

Some research papers dealing with loss of containment were also reviewed (e.g., /19/). These papers have both formed input to the development of scenarios, and as basis for assessment of to what extend the set of scenarios may be regarded as suitable.

One of the topics studied in The I-RISK project (/19/) was the potential for a release of a hazardous substance to the environment from chemical installations. Loss of containment (LOC) was defined as a discontinuity or loss of the pressure boundary between the hazardous substance and the environment, resulting in a release of hazardous substances.

A comparison of the coverage of the release scenarios developed in our project and the top level of the generic Master Logic Diagram for Loss of Containment developed in the I-RISK project (/19/) is shown in Figure 15.

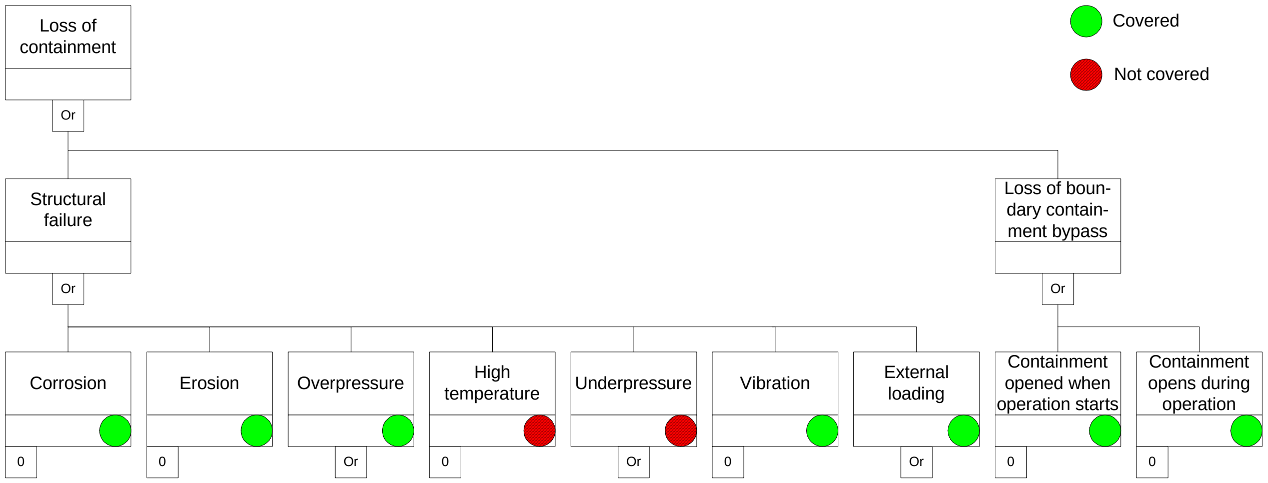

Figure 15. Comparison with the Master Logic Diagram of LoC from I-RISK (/19/).

As marked out with green circles in the figure, all causes in the Master Logic Diagram are covered in our release scenarios except “high temperature” and “underpressure”. These causes fall into the main group “process upsets” (or “process disturbances”) in Figure 11. The reason why there is no specific release scenarios defined for these causes is that the release statistics indicate that the contribution to the total release frequency from these causes is very low.

It should be noted that in the BORA project some release scenarios have been defined which are apparently not included in the above I-RISK Master Logic Diagram.

7. Overview of the set of release scenarios

Based on the results from the activities described in chapter 4 - 6, a set of release scenarios was developed.

The release scenarios were divided into seven (7) main groups and some of these groups were divided further into sub-categories:

1. Release during maintenance of HC-system (requiring disassembling)
   a. Release due to failure prior to or during disassembling of HC-system
   b. Release due to break-down of isolation system during maintenance
2. Release due to latent failure introduced during maintenance
   a. Release due to incorrect fitting of flanges or bolts during maintenance
   b. Release due to valve(s) in incorrect position after maintenance
   c. Release due to erroneous choice or installations of sealing device
3. Release due to operational failure during normal production
   a. Release due to maloperation of valve(s) during manual operation
   b. Release due to maloperation of temporary hoses.
   c. Release due to lack of preventive maintenance of water locks in the drain system
4. Release due to technical/physical failures
   a. Release due to degradation of valve sealing
   b. Release due to degradation of flange gasket
   c. Release due to loss of bolt tensioning
   d. Release due to degradation of welded pipes
   e. Release due to internal corrosion
   f. Release due to external corrosion
   g. Release due to erosion
5. Release due to process upsets
   a. Release due to overpressure
   b. Release due to overflow / overfilling
6. Release due to external events
   a. Release due to impact from falling object
   b. Release due to impact from bumping/collision
7. Release due to design related failures

Group 1 – 3 belong to the cause category human or operational failures, group 4 belong to the cause category technical failures, group 5 belong to the cause category process upsets / process parameters out of range, group 6 belongs to the cause category external events, while group 7 belongs to latent failures from design.

8. Comparison of the release scenarios with hydrocarbon release incidents

One purpose of this work has been to develop a set of release scenarios that are, if not exhaustive, at least covering the vast majority of releases.

One way to fulfil this purpose was to perform a comprehensive review in order to classify the 40 investigated hydrocarbon release incidents (ref. Table 1) according to the release scenarios defined in chapter 5.a.

Another activity performed in order to obtain a representative and comprehensive set of release scenarios was to submit the draft release scenarios for review by personnel from Hydro and the whole project group and discuss the draft scenarios in a project meeting. Only the final set of release scenarios are documented in this report. The draft release scenarios that formed the basis for the review are not included in this report.

This classification of the 40 hydrocarbon release incidents according to the release scenarios is shown in Table 2. The second column in the table contains cross-references to the accompanying accidents from the 40 hydrocarbon releases studied (ref. Table 1).

As seen in the table, 36 of 40 release incidents are suited to one of the release scenarios. The majority of the release incidents are operational related failures, and the largest contributor to the total amount of release incidents (14) is scenarios within the category "Releases due to latent failure introduced during maintenance". Further, the scenarios "Release due to degradation of valve sealing" and "Release due to failure prior to or during disassembling of HC-system" both are represented with 4 release incidents.

The other release incidents do not fit into some of the release scenarios due to different causes:

- Release incident no. 25 caused by plaque of salt on valve stem prevent valve closing.
- Release incident no. 26 caused by material failure in filter.
- Release incident no. 28 is leak from flexible riser and classified as not relevant.
- Release incident no. 33 not classified due to unknown cause.

From Table 2, we may also see that several of the scenarios (1b, 3b, 4b, 4c, 4g, 6a and 6b) are not represented in the sample of 40 release incidents. Nevertheless, due to release statistics, reports from other release incidents and input from different types of personnel, we think the presence of these scenarios are necessary to obtain a representative sample of release scenarios.

Table 2. Release scenarios versus release incidents.

Release scenario	**Release incident no.**
1. Release during maintenance of HC-system (require disassembling)	
a. Release due to failure prior to or during disassembling of HC-system	2, 7, 22, 31, 37
b. Release due to break-down of isolation system during maintenance	
2. Release due to latent failure introduced during maintenance	
a. Release due to incorrect fitting of flanges or bolts during maintenance	5, 9, 10, 11, 27, 30, 34, 39
b. Release due to valve(s) in incorrect position after maintenance	3, 14, 21, 23,
c. Release due to erroneous choice or installation of sealing device	13, 40
3. Release due to operational failure during normal production	
a. Release due to maloperation of valve(s) during manual operation	15, 24
b. Release due to maloperation of temporary hoses	
c. Release due to lack of water in water locks in the drain system	38
4. Release due to technical/physical failures	
a. Release due to degradation of valve sealing	8, 12, 19, 20, 29,
b. Release due to degradation of flange gasket	
c. Release due to loss of bolt tensioning	
d. Release due to degradation of welded pipes	16, 32
e. Release due to internal corrosion	18
f. Release due to external corrosion	1
g. Release due to erosion	
5. Release due to process upsets	
a. Release due to overpressure	6
b. Release due to overflow / overfilling	4, 17, 35
6. Release due to external events	
a. Release due to impact from falling object	
b. Release due to impact from bumping/collision	
7. Release due to design related failures (latent failures from design)	36

9. Detailed description of release scenarios

This chapter includes a detailed description of each release scenario in terms of:

- A table including a general description of the release scenario, the initiating event, factors influencing the initiating event, operational mode(s) when the failure is introduced, operational mode(s) at time of release, the barrier functions / systems available to prevent a release, and assumptions related to the scenario.
- A barrier block diagram illustrating the logical connection between the initiating event, the barrier functions / systems and the potential consequences / outcomes.

Some notes may be added to the scenario descriptions:

- The list of factors influencing the initiating events is not meant to be complete. The main purpose or the list is to provide input to the further analysis in later phases of the project.
- The description of the barrier systems does not include all the elements necessary to fulfil the functions. Some additional elements may be necessary. In several cases, only the detection is reflected, and the decision and the corrective action loop are not described. Nevertheless is the term barrier system used in the tables.

9.1 Release during maintenance of HC-system (requiring disassembling)

The release scenarios during maintenance due to disassembling of HC system include leaks related to failure of system and equipment isolation, depressurisation, draining, blinding, and purging prior to or during maintenance. These leaks are caused by failure or breakdown of the control system of isolation or of locked valves. Examples can be insufficient venting, draining or flushing, failure of the blinding, erroneous position of isolation valve, operation of an incorrect valve, etc. When disassembling (or opening) the HC system, e.g. when a pump is taken out for maintenance, these failures can cause loss of containment during the maintenance operation itself.

Two release scenarios are identified that may lead to release of hydrocarbons during maintenance requiring disassembling of the HC-systems:

a. Release due to failure prior to or during disassembling of HC-system
b. Release due to break-down of the isolation system during maintenance

Please note that scenario a. include failures introduced during preparatory activities as well as the disassembling operation itself. Scenario b. includes failures introduced after the isolation system is established.

9.1.1 Release due to failure prior to or during disassembling of HC-system

<table>
<tr><td colspan="2">Scenario name
Release due to failure prior to or during disassembling of HC-system</td></tr>
<tr><td colspan="2">General description
Releases caused by failures introduced prior to or during disassembling of HC system. These leaks are related to failures of system isolation, depressurisation, draining, blinding, and purging. The failures may be introduced prior to the disassembling (e.g., faulty isolation plans) or during implementation of the isolation plan (e.g., insufficient venting, draining or flushing, erroneous position of isolation valve or blinding, etc.). It should be noted that these failures result in releases occurring during the maintenance operation.</td></tr>
<tr><td colspan="2">Initiating event
Maintenance operations requiring disassembling of HC-system (for a given area on the installation)</td></tr>
<tr><td colspan="2">Factors influencing the initiating event
Maintenance philosophy, amount of equipment, technical condition</td></tr>
<tr><td colspan="2">Operational mode when failure is introduced
Failure introduced during isolation and/or disassembling, i.e., during maintenance, or during planning of maintenance (faulty isolation plan).</td></tr>
<tr><td colspan="2">Operational mode at time of release
During disassembling or later during the maintenance operation</td></tr>
<tr><td>Barrier functions
The release may be prevented if the following barrier functions are fulfilled:

• Develop isolation plan (adequate isolation, depressurisation, draining, blinding and purging) for safe disassembling
• Detection of failures in isolation plan

• Remove HC in segment before disassembling
• Verification of emptied system prior to disassembling</td><td>Barrier systems
The release may be prevented if the following barrier systems function:

• Isolation plan (i.e., plan for isolation, depressurization, draining, blinding, and purging) for the segment.
• System for WP
• System for verification isolation plan by area technicians prior to execution.
• System for isolation, draining, blinding, and purging according to plan
• If the plan is correct, potential failures during execution might be revealed by verification of performance according to plan (incl. verification of depressurized and purged system).
• If the plan is faulty, potential releases might be prevented by verification of depressurized and purged system.</td></tr>
<tr><td colspan="2">Assumptions
• Execution according to correct plan does not lead to releases.</td></tr>
</table>

Figure 16 shows the barrier block diagrams for the release scenario "Release due to failure prior to or during disassembling of HC-system".

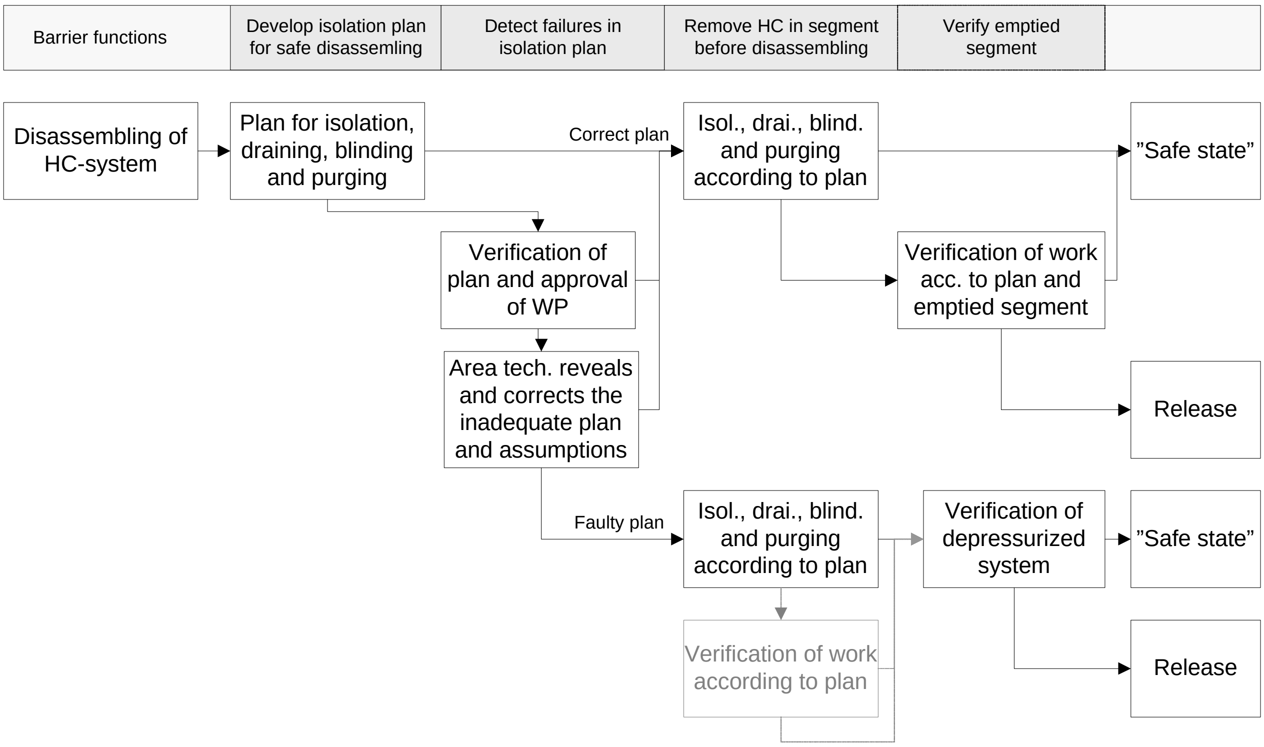

Figure 16. Release due to failure prior to or during disassembling of HC-system.

9.1.2 Release due to break-down of isolation system during maintenance

Scenario name Release due to break-down of isolation system during maintenance	
General description These releases are caused by failures that occur after the system of isolation is established. The isolation is originally adequate, but due to an operational (or technical) failure, the control system of isolation or of locked valves fails. Examples can be failures of the blinding (e.g. due to excessive internal pressure), internal leakage through valves or blindings, erroneous opening of a blinding, erroneous activation of isolation valves, etc. These failures may cause loss of containment during the maintenance operation.	
Initiating event Attempt to open isolation valve or blinding during maintenance (undesirable activation)	
Factors influencing the initiating event Competence, training, complexity of process, communication between personnel and between shifts, locking or labeling of valves/blindings, work permit	
Operational mode when failure is introduced During maintenance	
Operational mode at time of release During maintenance while systems or components are taken out of operation and isolated from the rest of the (pressurised) process system.	
Barrier functions The release may be prevented if the following safety functions are fulfilled: • Prevention of undesired activation of valve/ blinding	***Barrier systems*** The release might be prevented if the following barrier systems function: • Disconnection of actuator for automatic operated valves. • Locking of actuator for manual operated valves (in order to prevent manual operations). • Labelling of valves (in order to prevent manual operations).
Assumptions • Two possibilities are included in this scenario: the valve which is erroneously attempted operated is either automatically activated (from CCR or locally) or it is a manual hand operated valve.	

Figure 17 shows the barrier block diagram for the release scenario “Release due to break-down of isolation system during maintenance”.

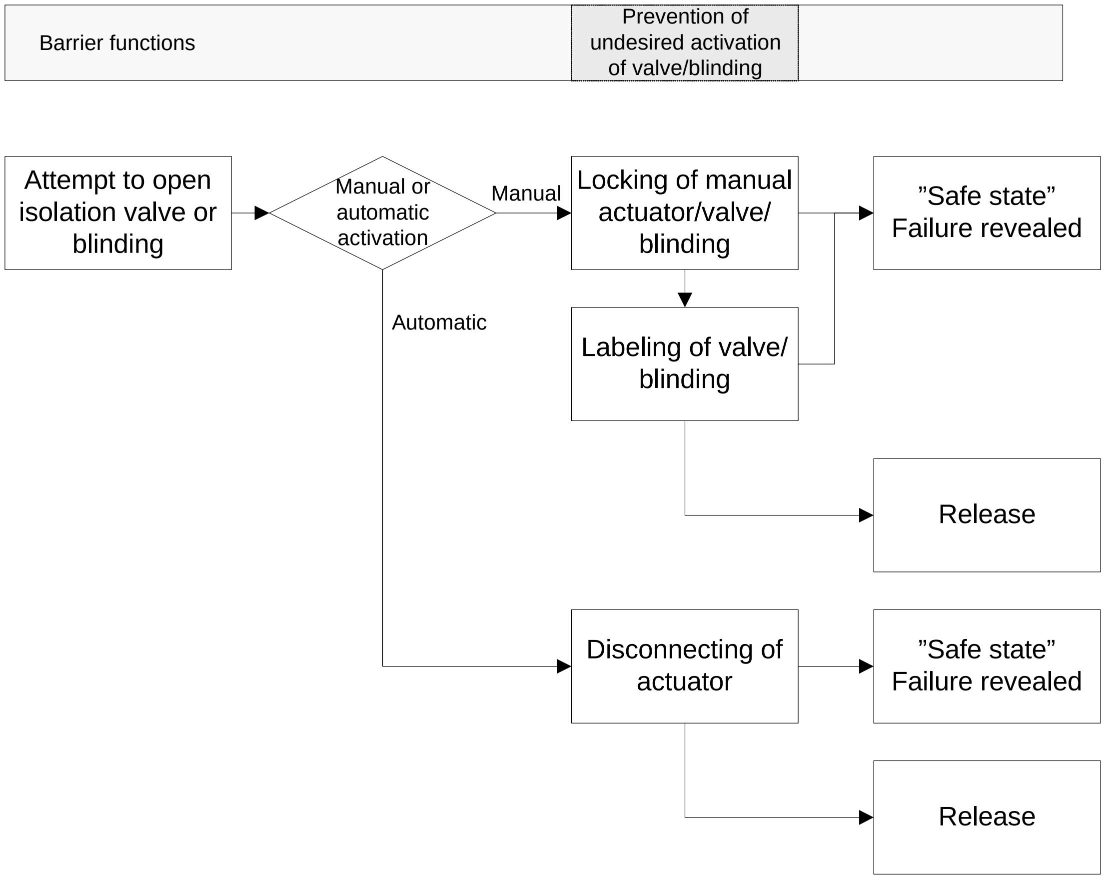

Figure 17. Release due to break-down of isolation system during maintenance.

9.2 Release due to latent failure introduced during maintenance

Releases due to latent failure introduced during maintenance include leaks caused by inadequate assembling and installation of equipment. Examples are an incorrectly fitted flange gasket, misalignment of flange faces during assembling of the bolts, insufficient tightening of bolts, valves left in the wrong position after maintenance, erroneous choice of sealing device, etc. This failure category may cause loss of containment during start-up or later during normal production (and even during shutdown). This category includes incorrectly fitting of equipment both in the field as well as in the workshop prior to assembling.

Three release scenarios are identified that may lead to release of hydrocarbons due to latent errors introduced during maintenance:

a. Release due to incorrect fitting of flanges or bolts during maintenance
b. Release due to valve(s) in incorrect position after maintenance
c. Release due to erroneous choice or installation of sealing device

9.2.1 Release due to incorrect fitting of flanges or bolts during maintenance

<table>
<tr><td colspan="2">Scenario name
Release due to incorrect fitting of flanges or bolts during maintenance</td></tr>
<tr><td colspan="2">General description
Release due to incorrect fitting of flanges or bolts during maintenance includes leaks due to tightening with too low or too high tension, misalignment of flange faces, damaged bolts, etc.</td></tr>
<tr><td colspan="2">Initiating event
Incorrect fitting of flanges or bolts during maintenance</td></tr>
<tr><td colspan="2">Factors influencing the initiating event
Competence, training, tools/equipment, procedures, accessibility/ maintainability, follow-up of tensioning, etc.</td></tr>
<tr><td colspan="2">Operational mode when failure is introduced
During maintenance</td></tr>
<tr><td colspan="2">Operational mode at time of release
During start-up after maintenance or later during normal production</td></tr>
<tr><td>Barrier functions
The release may be prevented if the following safety functions are fulfilled:

• Detection of incorrect fitting of flanges or bolts during maintenance

• Detection of release prior to normal production</td><td>Barrier systems
The release may be prevented if the following barrier systems functions:

• Formal self-control or use of checklists may contribute to detection of incorrect fitting of flanges or bolts prior to assembling of the system.
• Independent control (by other person) of work or inspection may reveal failures prior to assembling of the system or prior to the start-up.
• Formal leak tests may reveal potential failures prior to or during start-up (after assembling the system), but will not reveal all kind of failures that may lead to a release later during normal production. The leak test may be carried out in two ways: 1) by use of Nitrogen or 2) by use of manual detectors to detect hydrocarbons</td></tr>
<tr><td colspan="2">Assumptions
• The start-up procedure after maintenance may require follow-up of tensioning due to temperature variations in the process plant. This is not defined as a separate barrier function, but assumed to influence the initiating event.</td></tr>
</table>

The barrier block diagram for the release scenario “Release due to incorrect fitting of flanges or bolts during maintenance” is shown in Figure 18.

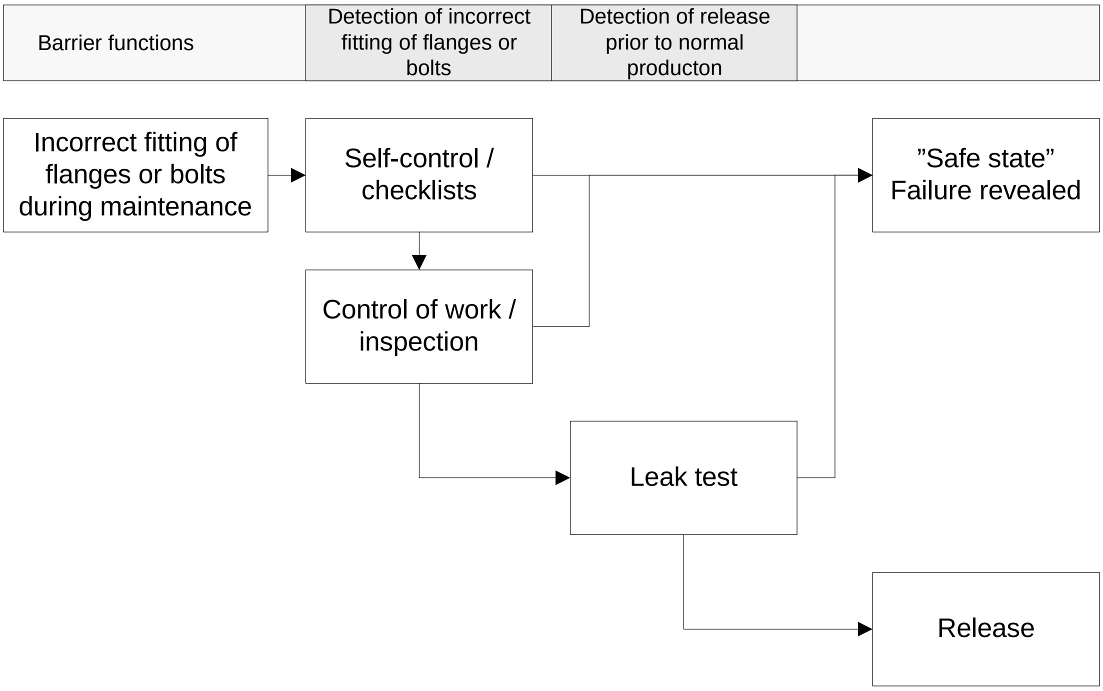

Figure 18. Release due to incorrect fitting of flanges or bolts during maintenance.

9.2.2 Release due to valve(s) in incorrect position after maintenance

<table>
<tr><td colspan="2">Scenario name
Release due to valve(s) in incorrect position after maintenance</td></tr>
<tr><td colspan="2">General description
Release due to valve(s) set in incorrect position after maintenance includes different types of valves in fail position, e.g., three way valves, block valves, isolation valves towards the flare system, valves to the drain system, etc.

Such failures can cause an immediate leak during start-up or it can alternatively cause a release e.g. when blowdown is initiated (due to inadvertent connection towards other system).</td></tr>
<tr><td colspan="2">Initiating event
Valve(s) in wrong position after maintenance</td></tr>
<tr><td colspan="2">Factors influencing the initiating event
Competence, training, system complexity, procedure / isolation plan, labelling of valves, etc.</td></tr>
<tr><td colspan="2">Operational mode when failure is introduced
During maintenance</td></tr>
<tr><td colspan="2">Operational mode at time of release
During start-up after maintenance, later during normal production, or during shutdown (e.g. during blowdown).</td></tr>
<tr><td>Barrier functions
The release may be prevented if the following safety functions are fulfilled:
Detection of valve(s) in wrong position
Detection of release prior to normal production</td><td>Barrier systems
The release might be prevented if the following barrier systems function:
Self control / use of checklist or “valve position overview” in order to detect possible valve(s) in fail position.
Independent control (by other person) of work / inspections of the position of relevant valve(s) before start-up.
Formal leak test may reveal leaks before start of normal production.</td></tr>
<tr><td colspan="2">Assumptions
The leak test may be carried out in two ways: 1) by use of Nitrogen or 2) by use of manual detectors to detect hydrocarbons</td></tr>
</table>

A barrier block diagram for the release scenario “Release due to valve(s) in incorrect position after maintenance” is shown in Figure 19.

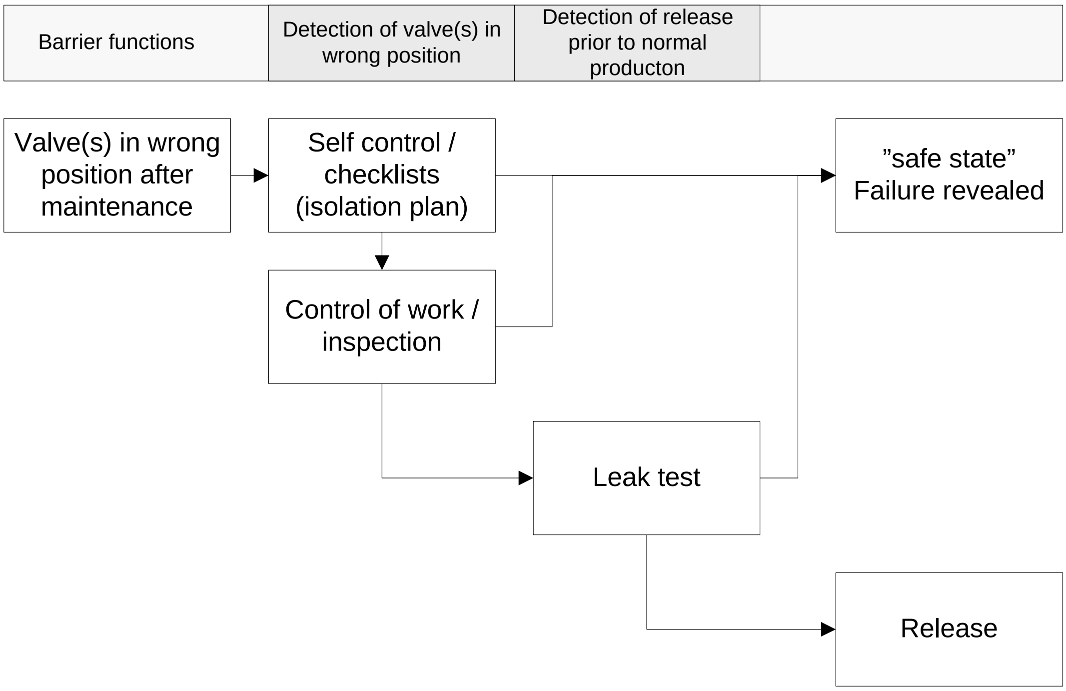

Figure 19. Release due to valve(s) in incorrect position after maintenance.

9.2.3Release due to erroneous choice or installation of sealing device

<table>
<tr><td colspan="2">Scenario name
Release due to erroneous choice or installation of sealing device</td></tr>
<tr><td colspan="2">General description
This category of releases include leaks caused by installation of wrong type of O-ring, selection and installation of wrong type of gaskets (e.g., incorrect material properties), erroneous installation of sealing device, installation of defect sealing devices/gasket, missing gasket/seals in flanges, etc.</td></tr>
<tr><td colspan="2">Initiating event
Erroneous choice or installation of sealing device</td></tr>
<tr><td colspan="2">Factors influencing the initiating event
Competence, training, complexity, tidiness/order in workshop, procedures/guidelines, labelling of sealing devices, lack of spares, etc.</td></tr>
<tr><td colspan="2">Operational mode when failure is introduced
During maintenance</td></tr>
<tr><td colspan="2">Operational mode at time of release
During start-up after maintenance, during normal production or during shutdown (e.g. due to low temperatures)</td></tr>
<tr><td>Barrier functions
The release may be prevented if the following safety functions are fulfilled:

• Detection of erroneous choice or installation of sealing device

• Detection of release prior to normal production</td><td>Barrier systems
The release might be prevented if the following barrier systems function:

• Self-control or use of checklists.
• Independent control (by other person) of work / inspection may be difficult because the inspection must be carried out before the flange assembling in order to see what type of sealing device that are used.
• Leak test prior to start-up of normal production. The leak test may be carried out in two ways: 1) by use of Nitrogen or 2) by use of manual detectors to detect hydrocarbons</td></tr>
<tr><td colspan="2">Assumptions
• Release caused by degradation of properties due to use of a wrong type of gasket/seal that lead to rapid degradation of the materiel properties are categorized into this scenario, cf. section 9.4.1 where the equipment is originally fit for purpose.
• Human or operational failures categorized as slips or mistakes.</td></tr>
</table>

Figure 20 shows a barrier block diagram for the release scenario “Release due to erroneous installation of sealing device”.

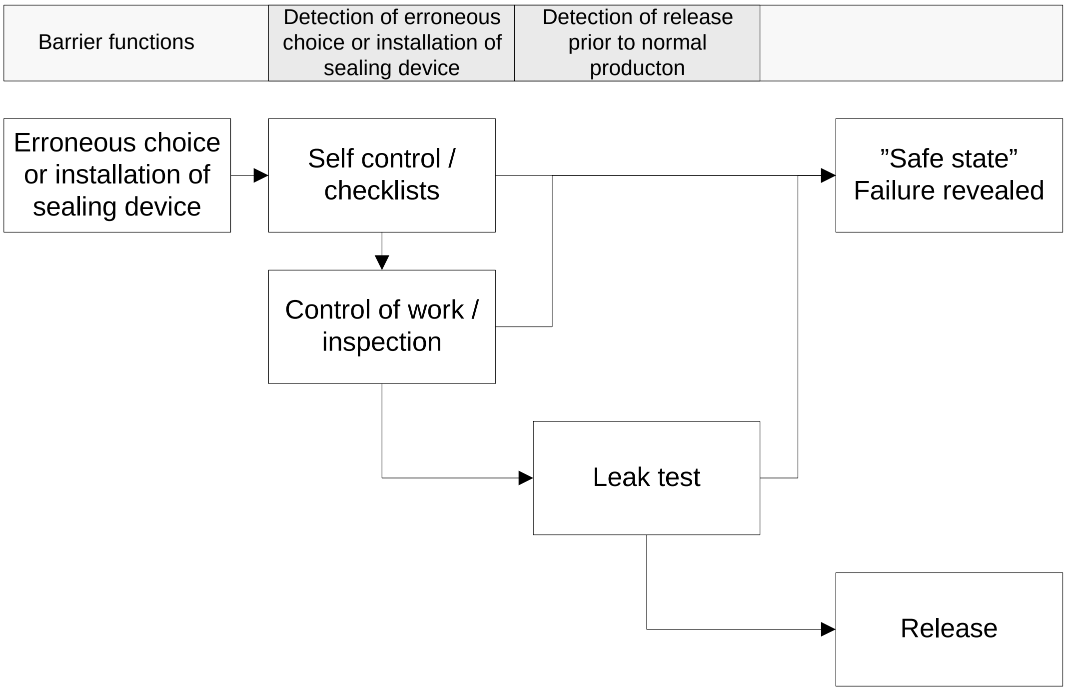

Figure 20. Release due to erroneous installation of sealing device.

9.3 Release due to operational failures during normal production

Releases due to operational failures during normal production include failures performed during normal operations like valve(s) in open position after taking of samples, isolation valves on drain system left in open position after removal of temporary connections, use of wrong type of hoses, lack of preventive maintenance of for example water locks in the drain system, etc.

Hence this category of releases represents limited manual operations which are actually performed while the production is running (as opposed to the failures described in section 9.1 and 9.2 which is introduced during larger maintenance operations).

Three release scenarios are identified that may lead to release of hydrocarbons due to operational failures during normal production:

a. Release due maloperation of valve(s) during manual operations.
b. Release due to maloperation of temporary hoses.
c. Release due to lack of water in water locks in the drain system.

9.3.1Release due to maloperation of valve(s) during manual operations

<table>
<tr><td colspan="2">Scenario name
Release due to maloperation of valve(s) during manual operation</td></tr>
<tr><td colspan="2">General description
Release due to maloperation of valve(s) in hydrocarbon systems during manual operations in the production phase. Examples are valve(s) left in open position after taking of samples performed by an area technician or laboratory technician, isolation valve on drain system left in open position after removal of temporary connections, failure during calibration of transmitters, etc.).</td></tr>
<tr><td colspan="2">Initiating event
Valve in wrong position after manual operation during “normal production”</td></tr>
<tr><td colspan="2">Factors influencing the initiating event
Competency, complexity, procedures, labelling of valves, design, short time limit, etc.</td></tr>
<tr><td colspan="2">Operational mode when failure is introduced
Normal production</td></tr>
<tr><td colspan="2">Operational mode at time of release
During normal production</td></tr>
<tr><td>Barrier functions
The release may be prevented if the following safety functions are fulfilled:
Detection of maloperation of valves</td><td>Barrier systems
The release might be prevented if the following safety barriers function:
Self control /checklist
Control of work / inspection performed by another person. If the area technician perform the manual operation himself, there will seldom be any kind of control of work / inspection.</td></tr>
<tr><td colspan="2">Assumptions
Taking of samples are usually performed by one person (area technician or laboratory technician).
No work permit is necessary.
The manual operations are usually regulated by procedures (e.g., taking of samples).
Depressurization of the system will usually prevent release.</td></tr>
</table>

A barrier block diagram for the release scenario “Release due to maloperation of valve(s) during manual operation” is shown in Figure 21.

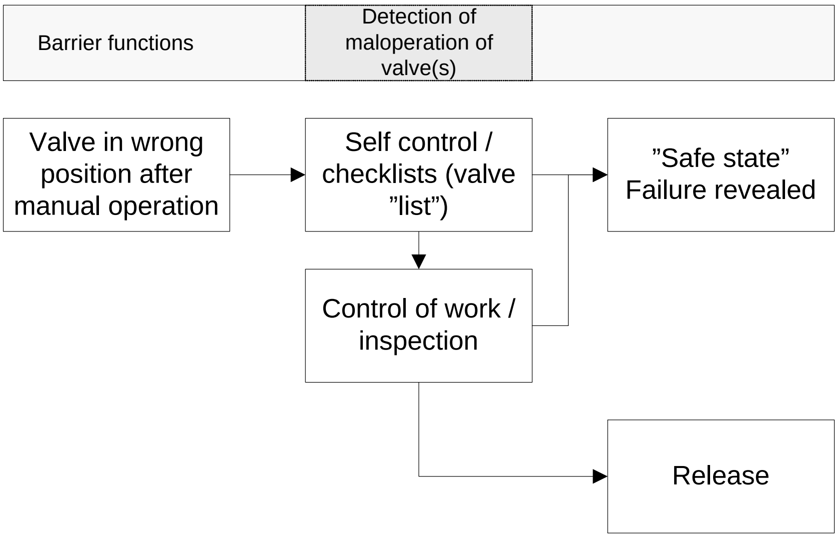

Figure 21. Release due to maloperation of valve(s) during manual operation.

9.3.2 Release due to maloperation of temporary hoses

Scenario name Release due to maloperation of temporary hoses	
General description Release due to maloperation of temporary hoses in the process plant. Examples are use of wrong type of hoses (e.g., wrong pressure rating) or failure during hook-up of the hoses.	
Initiating event Erroneous choice or hook-up of temporary hose	
Factors influencing the initiating event Competency, time pressure, labelling of hoses, complexity of process, etc.	
Operational mode when failure is introduced Normal production or maintenance	
Operational mode at time of release During normal production or during maintenance	
Barrier functions The release may be prevented if the following safety functions are fulfilled: • Detection of erroneous choice of hose • Detection of erroneous hook-up	***Barrier systems*** The release might be prevented if the following barrier systems function: • Self control / checklist • 3rd part control / inspection of work • Purging and pressure testing of hoses
Assumptions • Relases through temporary hoses due to a process valve left in wrong position is included in scenario 2.b	

Figure 22 shows a barrier block diagram for the release scenario “Release due to maloperation of temporary hoses”.

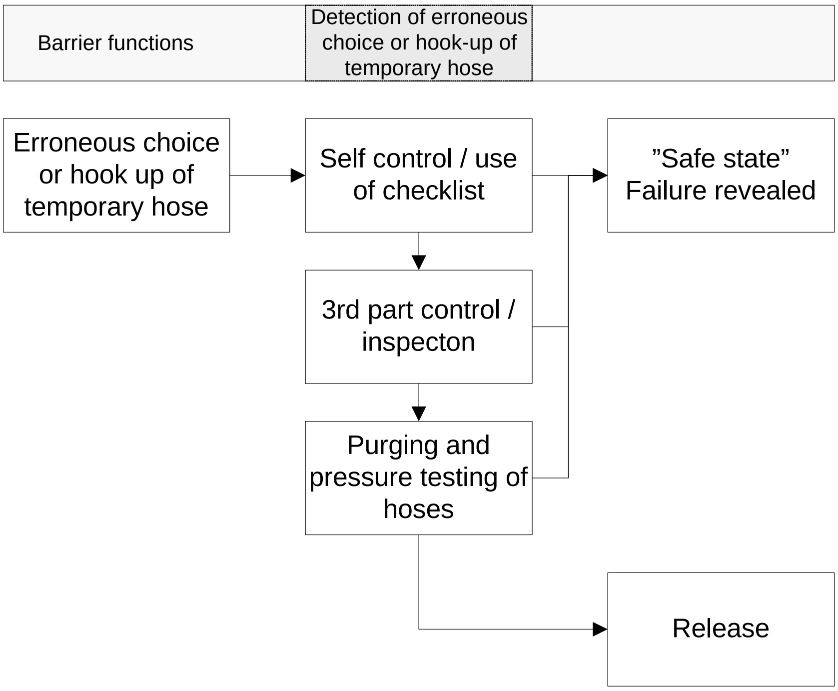

Figure 22. Release due to maloperation of temporary hoses.

9.3.3 Release due to lack of water in water locks in the drain system

Scenario name Release due to lack of water in water locks in the drain system	
General description Release due to lack of water in water locks in the drain system resulting in hydrocarbons escaping through the waterlock system.	
Initiating event Water level in water locks below critical level	
Factors influencing the initiating event Design, temperature, variation in pressure; complexity of process, etc.	
Operational mode when failure is introduced During normal production	
Operational mode at time of release During normal production	
Barrier functions The release may be prevented if the following safety functions are fulfilled: • Refilling of water when level is below critical level	***Barrier systems*** The release might be prevented if the following barrier systems function: • Preventive maintenance (PM), inspection and refilling if necessary.
Assumptions • Critical water level may be defined for each water lock. • A level controller in the water lock may give an alarm on low level. Such automatic detection is not assumed here.	

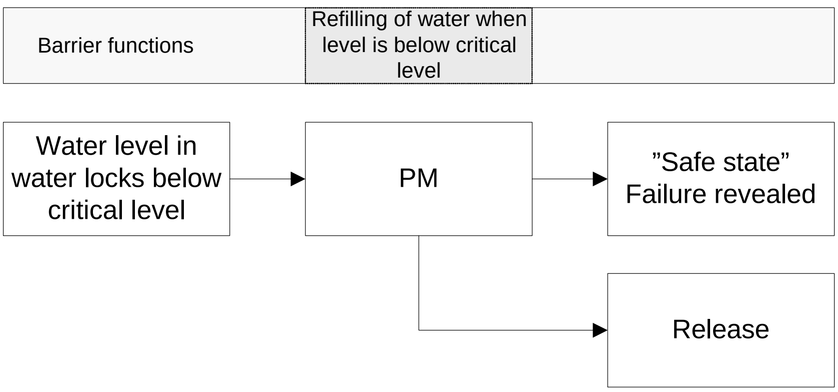

Figure 23. Release due to lack of PM of water locks in the drain system.

9.4 Release due to technical of physical failures

Leakage due to technical or physical failures includes leaks caused by degradation of properties, meaning loss of integrity by failure of equipment which was originally fit for purpose and was (originally) operated correctly. This category includes causes such as loss of flexibility in flange gaskets and valve stem packing, failure of seals, general “wear and tear”, corrosion, and erosion. Release due to fatigue/vibration is not defined as a separate scenario, but is categorised as a possible cause to scenario 4d) “Release due to degradation of welded pipe”.

Ageing/wear-out can result in more or less spontaneous leaks due to component failures, but can also result in loss of tensioning in flanges and “pack-boxes” on valves. The first type is the most difficult to detect since the equipment must normally be opened, whereas loss of tensioning in bolts can be detected and corrected by preventative maintenance such as tightening of bolts during production.

Release due to corrosion/erosion includes different types of internal and external corrosion on pipes and other types of equipment and external corrosion caused by corrosive environment (e.g., corrosion under isolation of equipment).

Seven scenarios are identified that may lead to release of hydrocarbons due to technical or physical failures:

a. Release due to degradation of valve sealing beyond
b. Release due to degradation of flange gasket
c. Release due to loss of bolt tensioning
d. Release due to degradation of welded pipes
e. Release due to internal corrosion
f. Release due to external corrosion
g. Release due to erosion

9.4.1 Release due to degradation of valve sealing

Scenario name Release due to degradation of valve sealing	
General description Releases due to mechanical or material degradation of valve sealing typically include loss of flexibility of valve stuffing box, degradation of properties of O-rings, etc.	
Initiating event Degradation of valve sealing beyond critical limit	
Factors influencing the initiating event Maintenance program, material properties, valve design, internal environment / fluid properties, etc.	
Operational mode when failure is introduced Usually during normal production	
Operational mode at time of release Usually during normal production	
Barrier functions The release may be prevented if the following safety functions are fulfilled: • Maintain the valve sealing to prevent degradation • Detect diffuse release	***Barrier systems*** The release may be prevented if the following safety barriers function: • Preventive maintenance of equipment (i.e., disassembling of valves). • Area based leak search may detect a minor release before the leak becomes significant.
Assumptions • Valve sealing was originally fit for purpose • Degradation beyond critical limit may be defined as the point at which, given that the valve was disassembled, the sealing devices would have been replaced / repaired • By the term “minor” release, we here mean a “pinhole” type of leak which does not represent any safety risk • It is here assumed that a minor (pinhole) release will have a potential to develop into a larger release if it is not detected • Significant release is defined as release size > 0,1 kg/s (or releases included in QRA)	

A barrier block diagram for the release scenario “Release due to degradation of valve sealing” is shown in Figure 24.

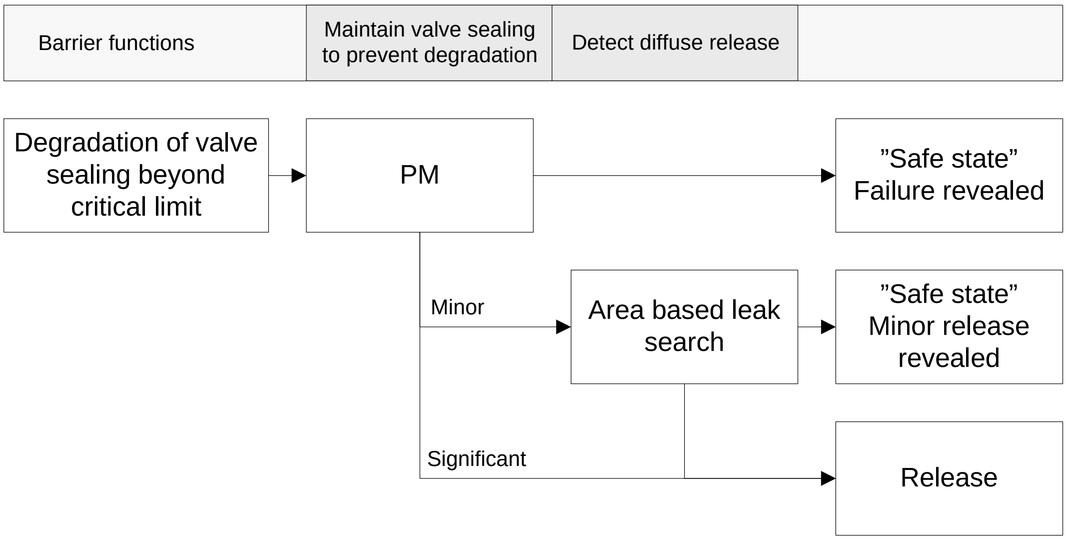

Figure 24. Release due to degradation of valve sealing.

9.4.2 Release due to degradation of flange gasket

<table>
<tr><td colspan="2">Scenario name
Release due to degradation of flange gasket</td></tr>
<tr><td colspan="2">General description
Releases due to degradation of flange gasket properties typically include releases caused by degradation of material properties of gaskets/seals (e.g. loss of flexibility).</td></tr>
<tr><td colspan="2">Initiating event
Degradation of flange gasket beyond critical limit</td></tr>
<tr><td colspan="2">Factors influencing the initiating event
Maintenance program, material properties, internal environment / fluid properties, etc.</td></tr>
<tr><td colspan="2">Operational mode when failure is introduced
Usually during normal production</td></tr>
<tr><td colspan="2">Operational mode at time of release
Usually during normal production</td></tr>
<tr><td>Barrier functions
The release may be prevented if the following safety functions are fulfilled:

• Maintenance of flange gasket to prevent degradation
• Detect diffuse release</td><td>Barrier systems
The release might be prevented if the following safety barriers function:

• Preventive maintenance

• Area based leak search in order to detect minor leaks before they evolve into notable leaks.</td></tr>
<tr><td colspan="2">Assumptions
• Degradation beyond critical limit may be defined as the point at which, given that the flange was disassembled, the gasket would have been replaced.
• By the term “minor” release, we here mean a “pinhole” type of leak which does not represent any safety risk.
• It is assumed that minor (pinhole) leaks may evolve into notable leaks after some time.</td></tr>
</table>

A barrier block diagram for the release scenario “Release due to degradation of flange gasket” is shown in Figure 25.

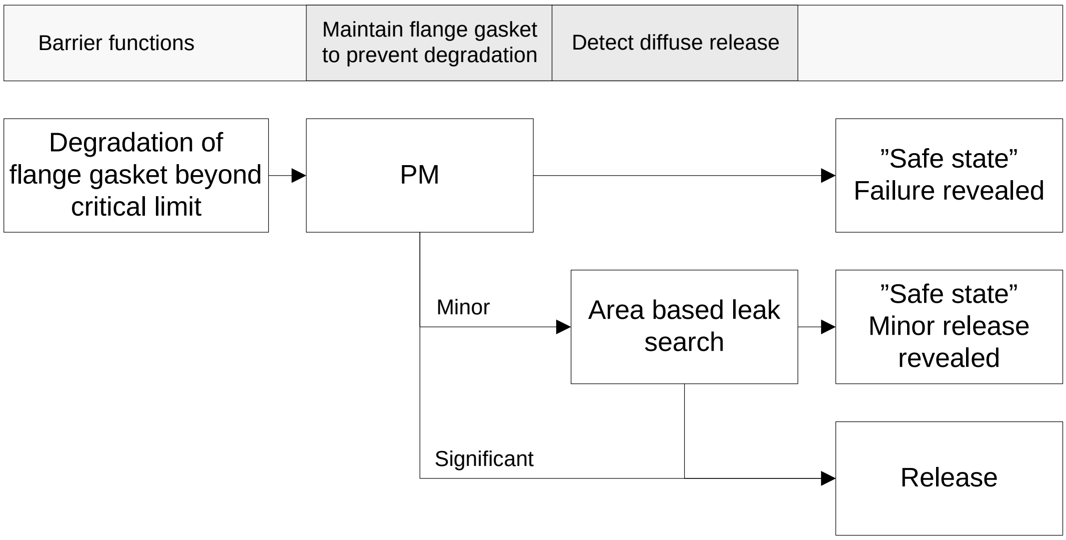

Figure 25. Release due to degradation of flange gasket.

9.4.3 Release due to loss of bolt tensioning

<table>
<tr><td colspan="2">Scenario name
Release due to loss of bolt tensioning</td></tr>
<tr><td colspan="2">General description
Releases due to loss of bolt tensioning include leaks from flanges, valves, instrument couplings, etc., due to loss of bolt tensioning after some time. The bolt tensioning was originally adequate, i.e. the leak will occur after some time (and not during start-up or shortly after start-up of production).</td></tr>
<tr><td colspan="2">Initiating event
Loss of bolt tensioning (due to ageing / wear-out)</td></tr>
<tr><td colspan="2">Factors influencing the initiating event
• Maintenance program including follow-up of bolt tensioning
• Procedures for locking of bolts
• Use of lock-tite
• Process conditions</td></tr>
<tr><td colspan="2">Operational mode when failure is introduced
During normal production</td></tr>
<tr><td colspan="2">Operational mode at time of release
Usually during normal production</td></tr>
<tr><td>Barrier functions
The release may be prevented if the following safety functions are fulfilled:
• Follow-up of bolt tensioning to prevent release.
• Detect diffuse release</td><td>Barrier functions
The release might be prevented if the following safety barriers function:
• Preventive maintenance (inspection and follow-up of tensioning) Area based leak search may detect minor releases before they develop into significant leaks.
• Area based leak search in order to detect minor leaks before they evolve into notable leaks.</td></tr>
<tr><td colspan="2">Assumptions
• The bolt tensioning was originally adequate.
• “Loss of bolt tensioning” is defined as the point at which, given that the bolts were inspected, they would have been “tightened”.
• By the term “minor” release, we here mean a “pinhole” type of leak which does not represent any safety risk.
• It is assumed that minor (pinhole) leaks may evolve into notable leaks after some time.</td></tr>
</table>

Figure 26 shows a barrier block diagram for the release scenario “Release due to loss of bolt tensioning”.

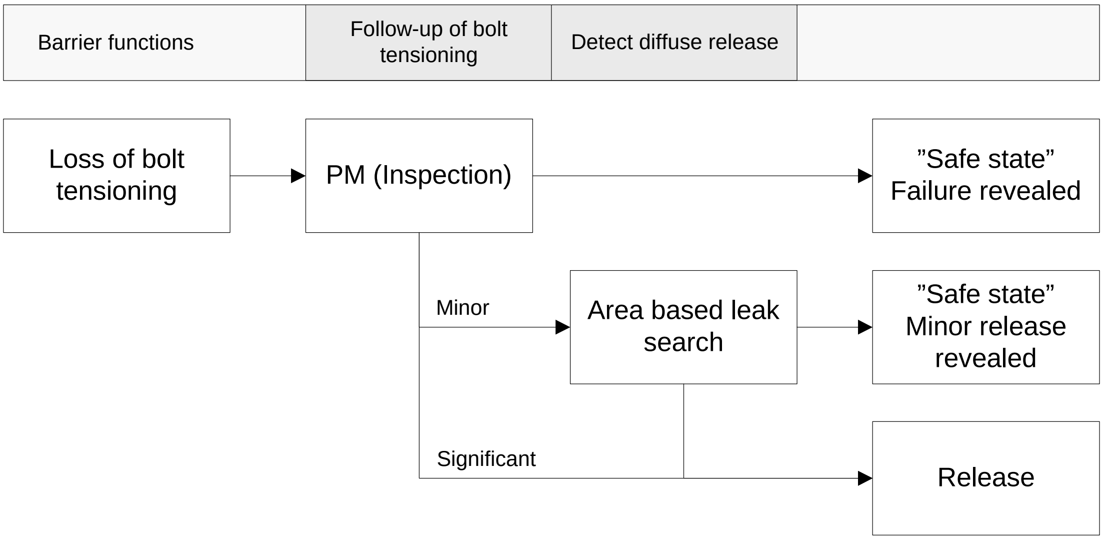

Figure 26. Release due to loss of bolt tensioning.

9.4.4 Release due to degradation of welded pipe

Scenario name
Release due to degradation of welded pipe

General description
This category of releases includes leaks from welds due to degradation. Examples can be a leak from welded instrument or valve, or from a weld in a pipe bend.

Initiating event
Degradation of weld beyond critical limit

Factors influencing the initiating event
Inspection program, material properties, vibration, internal environment / fluid properties, quality of work, supporting of instrument tubing, etc.

Operational mode when failure is introduced
During normal production

Operational mode at time of release
During normal production or during start-up or shut down.

Barrier functions	***Barrier systems***
The release may be prevented if the following safety functions are fulfilled: • Detection of weld degradation • Detection of diffuse HC release	The release might be prevented if the following barriers systems function: • Internal inspection program • External inspection • Area based leak search may detect minor releases before they develop into significant leaks.

Assumptions
- Degradation beyond critical limit may be defined as the point at which, given that an inspection was performed, a repair / maintenance action would have been initiated.
- Vibration may be the most usual cause of this type of release.

Figure 27 shows the barrier block diagram for the release scenario “Release due to degradation of welded pipe”.

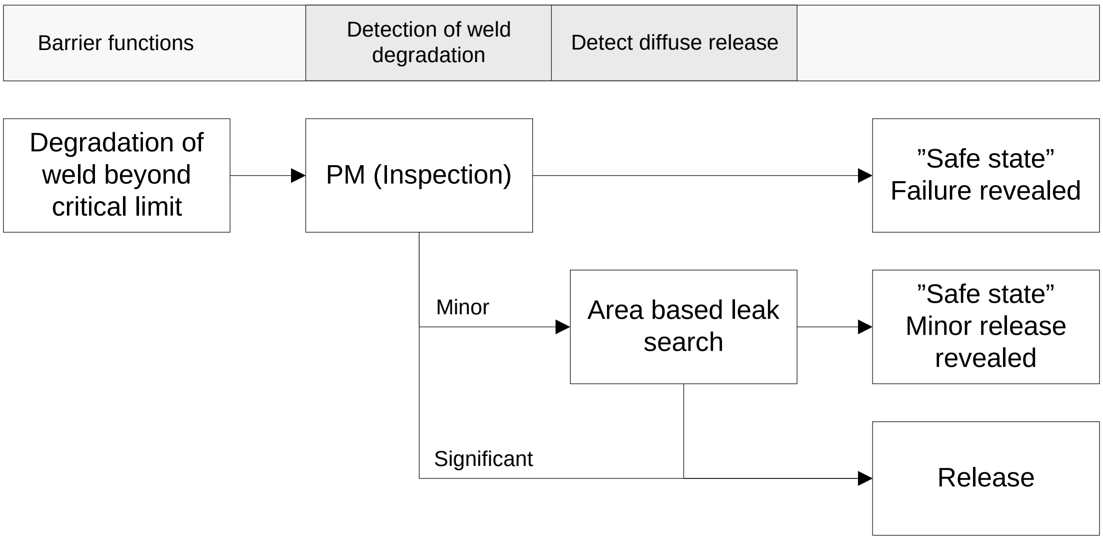

Figure 27. Release due to degradation of welded pipe.

9.4.5 Release due to internal corrosion

<table>
<tr><td colspan="2">Scenario name
Release due to internal corrosion</td></tr>
<tr><td colspan="2">General description
Releases caused by internal corrosion (different types of corrosion)</td></tr>
<tr><td colspan="2">Initiating event
Internal corrosion beyond critical limit</td></tr>
<tr><td colspan="2">Factors influencing the initiating event
Corrosion resistance of material, corrosion coating, chemical injection / corrosion inhibitor, internal fluid properties, inspection programs, allowances / safety margins, etc.</td></tr>
<tr><td colspan="2">Operational mode when failure is introduced
During normal production (after some time)</td></tr>
<tr><td colspan="2">Operational mode at time of release
During normal production or during process disturbances (resulting in e.g. increased pressures).</td></tr>
<tr><td>Barrier functions
The release may be prevented if the following safety functions are fulfilled:
• Detection of internal corrosion to prevent release
• Detection of diffuse HC release</td><td>Barrier systems
The release might be prevented if the following safety barriers function:
• Condition monitoring of equipment to detect potential corrosion / erosion.
• Inspection / NDT programme to detect potential corrosion / erosion.
• Area based leak search may detect minor releases before they develop into significant leaks.</td></tr>
<tr><td colspan="2">Assumptions
• Critical limit may be defined as corrosion beyond the acceptable allowance margins.
• The choice of inspection points is very important for the possibility to detect the corrosion.</td></tr>
</table>

Figure 29 shows a barrier block diagram for the release scenario “Release due to internal corrosion”.

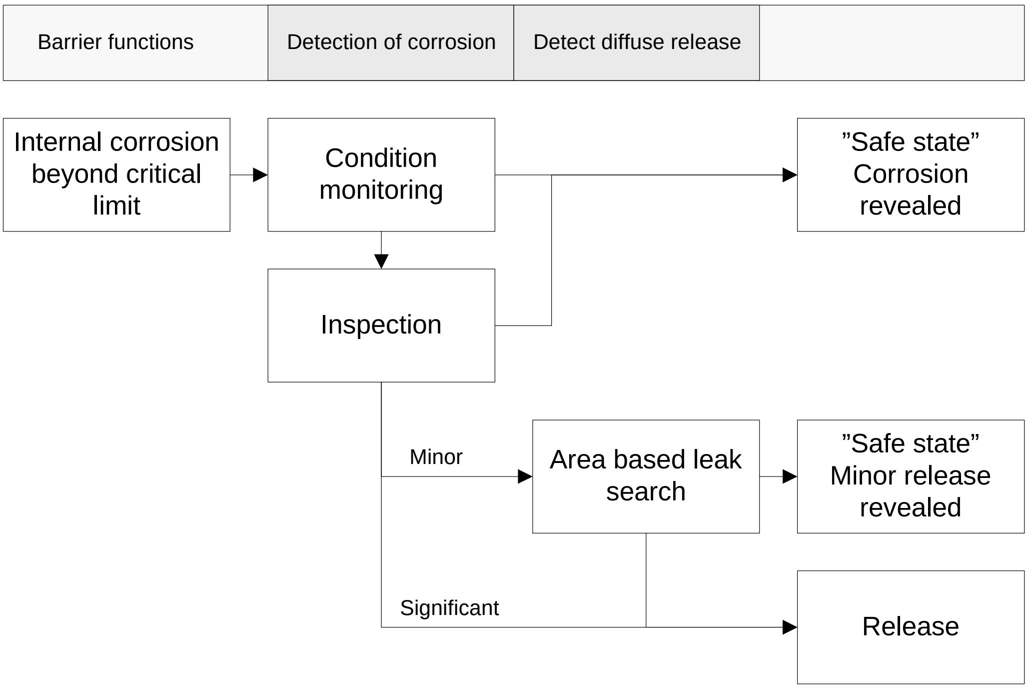

Figure 28. Release due to internal corrosion.

9.4.6 Release due to external corrosion

<table>
<tr><td colspan="2">Scenario name
Release due to external corrosion</td></tr>
<tr><td colspan="2">General description
Releases due to external corrosion, typically caused by piping or vessels being passively protected (fire protection, thermal protection, etc.)</td></tr>
<tr><td colspan="2">Initiating event
External corrosion beyond critical limit</td></tr>
<tr><td colspan="2">Factors influencing the initiating event
Degree of passive protection, material selection (both protection material and steel), external environment, inspection programs, etc.</td></tr>
<tr><td colspan="2">Operational mode when failure is introduced
During normal production</td></tr>
<tr><td colspan="2">Operational mode at time of release
During normal production or during process disturbances (resulting in e.g. increased pressures).</td></tr>
<tr><td>Barrier functions
The release may be prevented if the following safety functions are fulfilled:

• Detection of external corrosion to prevent HC release

• Detection of diffuse HC release</td><td>Barrier systems
The release might be prevented if the following barrier systems function:

• Inspection programme to detect potential external corrosion. Need to remove the isolation in order to detect the corrosion. Both visual inspection and thickness measurement. External corrosion can be detected incidentally during maintenance on near-by equipment and/or removal of isolation materials
• Area based leak search may detect minor releases before they develop into significant leaks.</td></tr>
<tr><td colspan="2">Assumptions
• Critical limit may be defined as corrosion beyond the acceptable allowance margins.</td></tr>
</table>

Figure 29 shows a barrier block diagram for the release scenario “Release due to external corrosion”.

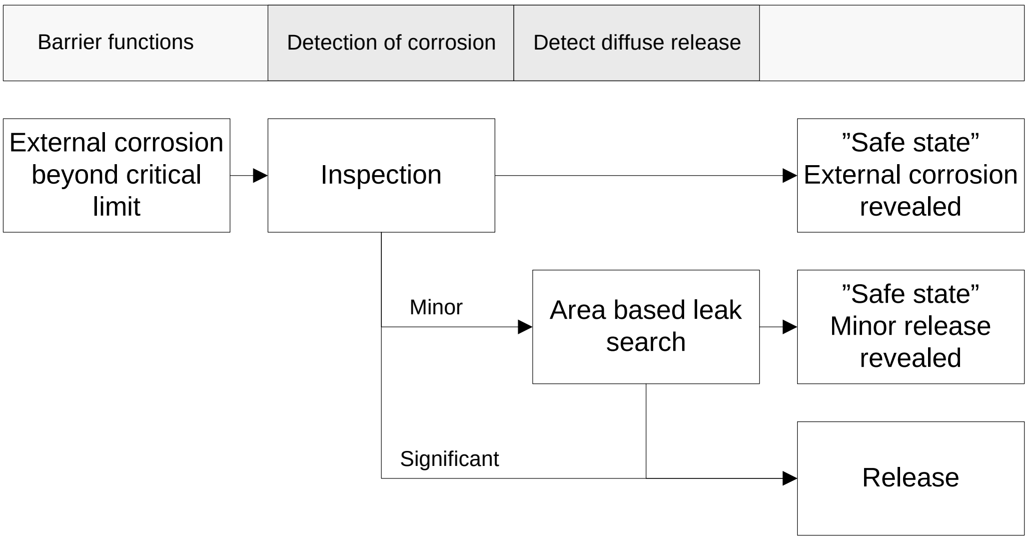

Figure 29. Release due to external corrosion.

9.4.7 Release due to erosion

<table>
<tr><td colspan="2">Scenario name
Release due to erosion</td></tr>
<tr><td colspan="2">General description
Releases due to erosion, typically caused by production of sand from the reservoir.</td></tr>
<tr><td colspan="2">Initiating event
Erosion beyond critical limit</td></tr>
<tr><td colspan="2">Factors influencing the initiating event
Reservoir conditions, quality of sand filters, monitoring of the content of sand, design of pipes, etc.</td></tr>
<tr><td colspan="2">Operational mode when failure is introduced
During normal production</td></tr>
<tr><td colspan="2">Operational mode at time of release
Usually during normal production</td></tr>
<tr><td>Barrier functions
The release may be prevented if the following safety functions are fulfilled:

• Detection of erosion to prevent HC release

• Detection of diffuse HC release</td><td>Barrier systems
The release might be prevented if the following barrier systems function:

• Condition monitoring of equipment to detect erosion.
• Inspection / NDT programme to detect potential erosion. The choice of inspection points is very important for the possibility to detect the erosion.
• Area based leak search may detect minor releases before they develop into significant leaks.</td></tr>
<tr><td colspan="2">Assumptions
• Critical limit may be defined as erosion beyond the acceptable allowance margins.</td></tr>
</table>

Figure 30 shows a barrier block diagram for the release scenario “Release due to erosion”.

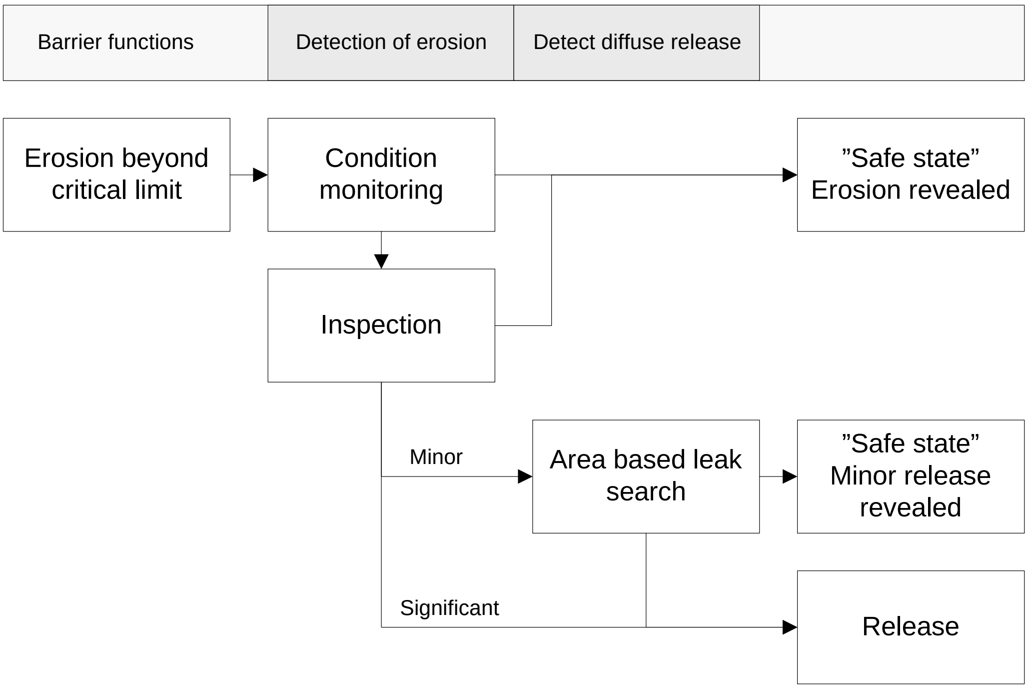

Figure 30. Release due to erosion.

9.5 Release due to process upset

The release scenarios due to process upsets cover upsets like overpressure, underpressure, overflow, overfilling, high temperature, low temperature, etc. Releases due to overpressure describe the situations where the internal pressure increase to such a high level that stresses induced on the containment overcome its strength. This may result in a blown-out flange gasket, a damaged instrument connection, etc. Overpressure may be created by increased internal pressure or pressure shock due to different reasons.

Release due to overflow / overfilling may occur in tanks having some kind of connection either directly to atmosphere, or via another system to atmosphere (e.g. closed drain).

Two release scenarios are identified that may lead to release of hydrocarbons due to process upsets:

a. Release due to overpressure
b. Release due to overflow/overfilling

9.5.1 Release due overpressure

<table>
<tr><td colspan="2">Scenario name
Release due to overpressure</td></tr>
<tr><td colspan="2">General description
Releases due to overpressure describe the situations where the internal pressure increase to such a high level that stresses induced on the containment overcome its strength. Overpressure may be created by increased internal pressure or pressure shock.</td></tr>
<tr><td colspan="2">Initiating event
Pressure above critical limit (e.g. PAHH setpoint)</td></tr>
<tr><td colspan="2">Factors influencing the initiating event
Various operational conditions</td></tr>
<tr><td colspan="2">Operational mode when failure is introduced
During start-up, shutdown or during normal production.</td></tr>
<tr><td colspan="2">Operational mode at time of release
During normal production when process disturbances occur.
Also during start up or during shutdown where e.g. hydrate formation can cause blockage and subsequent possibilities for overpressure.</td></tr>
<tr><td>Barrier functions
The release may be prevented if the following safety functions are fulfilled:

• Close inflow(stop additional supply of HC)

• Release of HC (pressure relief)

• Residual strength</td><td>Barrier systems
The release might be prevented if the following barrier systems function:

• Primary protection from overpressure in a pressure component should be provided by a PSH protection system to shut off inflow (PSD). If a vessel is heated, the PSH sensor should also shut off the fuel or source of heat. Primary protection for atmospheric components should be provided by an adequate vent system (/14/).
• Secondary protection from overpressure in a pressure component should be provided by a PSV. Secondary protection for atmospheric components should be provided by a second vent. The second vent may be identical to the primary vent, a gauge hatch with a self-contained PSV or an independent PSV. Alternatively an instrument based system may be used for primary and secondary protection provided it is implemented according to IEC 61508 (/14/).
• Depending on the pressure conditions and the design, the residual strength of the steel may also prevent release. Whether the</td></tr>
</table>

	residual strength in the steel is sufficient to prevent overpressure will depend on the maximum obtainable pressure in the segment (i.e. max. shut in pressure)

Assumptions

- Critical limit (PAHH) is a system specific value, however, normally the PAHH set point will be related to the design pressure of the vessel / piping.
- Limitations on flare capacity require sequential blowdown on several installations.
- This scenario will be most relevant to consider in cases where equipment are not conventionally protected, e.g. in cases where a HIPPS solution, or other type of instrumented protection is selected as the second level of protection.

A barrier block diagram for the release scenario "Release due to overpressure" is shown in Figure 31.

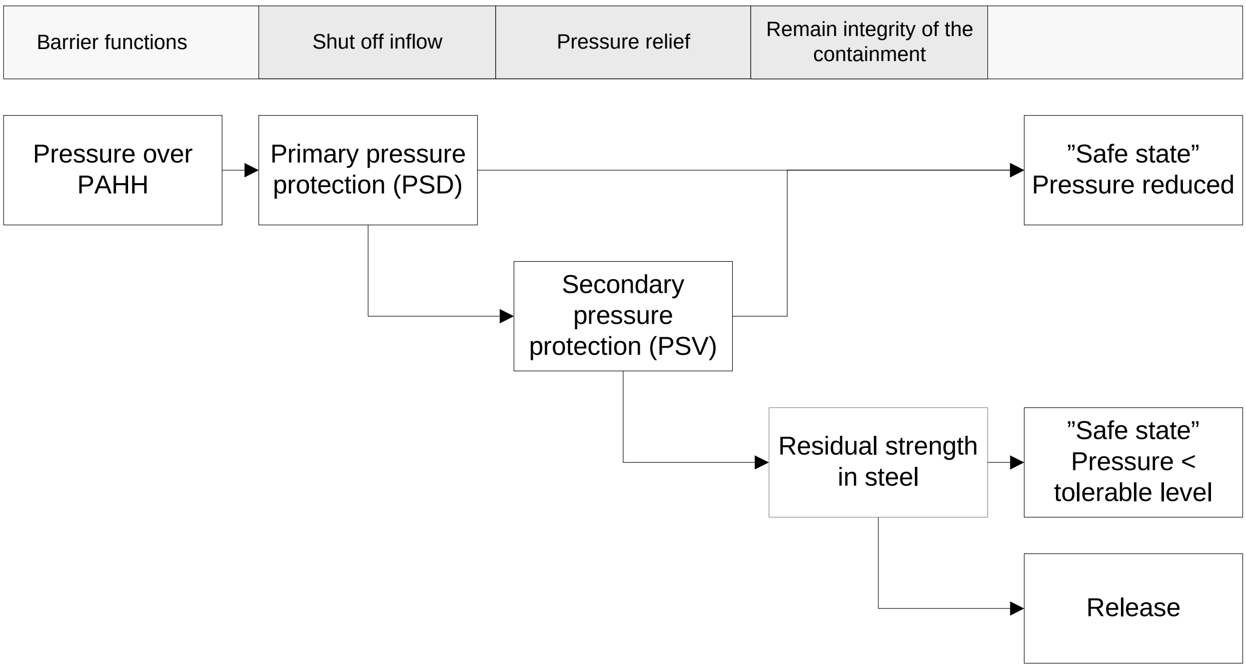

Figure 31. Release due to overpressure.

9.5.2 Release due to overflow / overfilling

Based on the review of the 40 accidents and also a number of additional Synergi events, it appears that overfilling of atmospheric tanks / vessels is the most frequently occurring type of event in the “process upset category”. Typically, there will be some automatic protection, e.g. giving a high level alarm, and in addition some kind of operational error may have occurred.

<table>
<tr><td colspan="2">Scenario name
Release due to overflow / overfilling</td></tr>
<tr><td colspan="2">General description
Release due to overflow / overfilling may occur in tanks having some kind of connection either directly to atmosphere, or via another system to atmosphere (e.g. closed drain). Typical examples are diesel tanks, oil storage tanks, methanol tanks, process vessels, etc
.</td></tr>
<tr><td colspan="2">Initiating event
Level above critical level</td></tr>
<tr><td colspan="2">Factors influencing the initiating event
Operational conditions, competency, complexity, procedures, design, principle of level sensor</td></tr>
<tr><td colspan="2">Operational mode when failure is introduced
During normal production, start-up or shutdown.</td></tr>
<tr><td colspan="2">Operational mode
During normal production, start up or shutdown.</td></tr>
<tr><td>Barrier functions
The release might be prevented if the following barrier functions are fulfilled:
Shut off inflow
Release / draining</td><td>Barrier functions
The release might be prevented if the following barrier systems function (/14/):
Primary protection from liquid overflow should be provided by an LSH sensor to shut off inflow into the component (PSD).
Secondary protection from liquid overflow to the atmosphere should be provided by the ESSs. Secondary protection from liquid overflow to a downstream component should be provided by safety devices on the downstream component. Alternatively an instrument based system may be used for primary and secondary protection system providing it is implemented according to IEC 61508.</td></tr>
<tr><td colspan="2">Assumptions
LAHH is system specific.
Be aware of that sometimes a high level indication causes an immediate shutdown, and sometimes only an alarm to the operator.
Often these overflow/overfilling is caused by a combination of technical and operational failures.</td></tr>
</table>

A barrier block diagram for the release scenario "Release due to overflow" is shown in Figure 32.

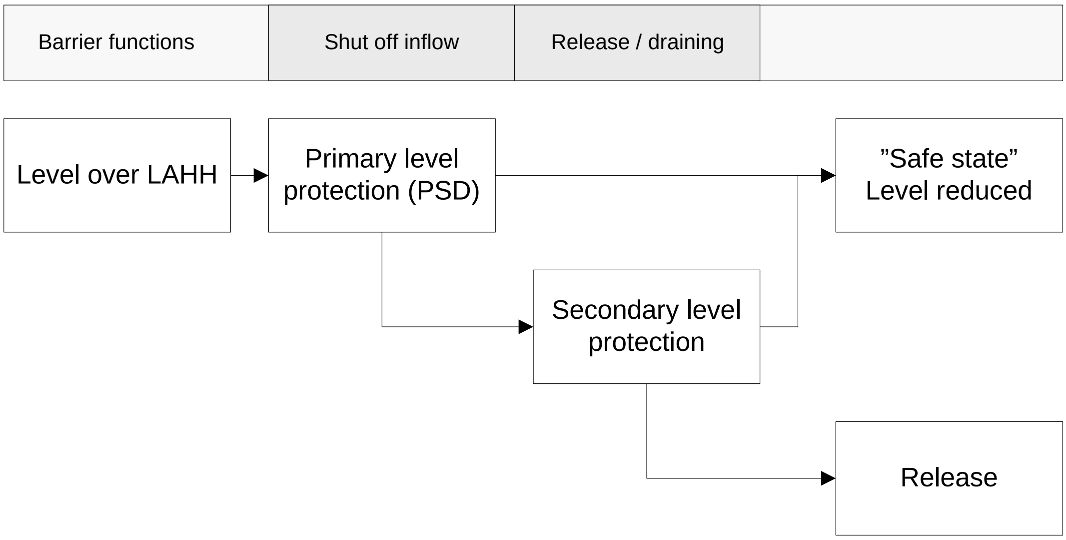

Figure 32. Release due to overflow / overfilling.

9.6 Release due to external events

Release caused by structural failure of the containment due to external loads occurs whenever external loads induce stresses to the containment that exceed the strength of the material properties.

Two types of initiating events are identified:

a. Falling object
b. Bumping/collision

These events are not further developed here, due to statistical evidence showing a very low occurrence of such releases. Furthermore, it will be more natural to consider such releases as a secondary effect / consequence from the initiating event "dropped object" or "collision".

9.7 Release due to design related failures

Not considered here, due to focus in project on operational risks.

10. Overview of initiating events and barriers

This chapter contains a summary of the defined initiating events and the barrier functions aimed to prevent release of hydrocarbons and how these functions are realized by barrier systems.

10.1 List of initiating events

The following initiating events are defined (grouped by scenarios):

Release during maintenance of HC-system (requiring disassembling)

1. Maintenance operations requiring disassembling of HC-system
2. Attempt to open isolation valve or blinding during maintenance (undesirable activation)

Release due to latent failure introduced during maintenance

3. Incorrect fitting of flanges or bolts during maintenance
4. Valve(s) in wrong position after maintenance
5. Erroneous choice or installation of sealing device

Release due to operational failure during normal production

6. Valve in wrong position after manual operation during “normal production”
7. Erroneous choice or hook-up of temporary hose
8. Water level in water locks below critical level

Release due to technical/physical failures

9. Degradation of valve sealing beyond critical limit
10. Degradation of flange gasket beyond critical limit
11. Loss of bolt tensioning (due to ageing / wear-out)
12. Degradation of weld beyond critical limit
13. Internal corrosion beyond critical limit
14. External corrosion beyond critical limit
15. Erosion beyond critical limit

Release due to process upsets

16. Pressure above critical limit (e.g. PAHH setpoint)
17. Level above critical level

Release due to external events *Not analysed*
Release due to design related failures *Not analysed*

10.2 List of barriers aimed to prevent release of hydrocarbons

Barriers functions aimed to prevent release of hydrocarbons and the barrier systems that realize these barrier functions are summarized in Table 3.

Table 3. Summary of barrier functions and barrier systems.

Barrier functions	Barrier systems
1. Release during maintenance of HC-system (requiring disassembling)	
• Develop isolation plan for safe disassembling	• System for development of isolation plan.
• Detection of failures in isolation plan	• System for Work Permits • System for verification isolation plan by area technicians prior to execution.
• Remove HC in segment before disassembling	• System for isolation, draining, blinding, and purging according to plan
• Verification of emptied system prior to disassembling	• System for verification of performance according to plan (incl. verification of depressurized and purged system). • System for verification of depressurized and purged system.
• Prevention of undesired activation of valve during maintenance	• Systems for disconnection of actuator for automatic operated valves. • System for locking of actuator for manual operated valves • System for labeling of valves (to prevent manual operation)
2. Release due to latent failure introduced during maintenance	
• Detection of incorrect fitting of flanges or bolts • Detection of valve(s) in wrong position • Detection of erroneous choice or installation of sealing device	• System for self-control / use of checklists • System for 3rd part control of work/ inspection
• Detection of release prior to normal production	• System for formal leak test
3. Release due to operational failure during normal production	
• Detection of maloperation of valves • Detection of erroneous choice of hose • Detection of erroneous hook-up of hose • Refilling of water in water locks when level is below critical level	• System for self control / use of checklist • System for 3rd part control / inspection of work • System for purging and pressure testing of hoses • PM (inspection and refilling if necessary)
4. Release due to technical/physical failures	
• Maintain the valve sealing to prevent degradation	• PM of equipment (i.e., disassembling of valves)
• Maintenance of flange gasket to prevent degradation	• PM of flange (gaskets)
• Follow-up of bolt tensioning to prevent release	• PM (program for inspection and follow-up of tensioning)
• Detection of weld degradation	• PM (program for internal inspection of welds) • PM (program for external inspection of welds)
• Detection of internal corrosion	• System for condition monitoring of equipment • PM (program for internal inspection (corrosion))
• Detection of external corrosion	• PM (program for external inspection (corrosion))
• Detection of erosion	• System for condition monitoring of equipment • PM (program for internal inspection (erosion))
• Detect diffuse HC-release	• System for area based leak search
5. Release due to process upsets	
• Close inflow (stop additional supply of HC)	• PSD to shut off inflow
• Release of HC (pressure relief)	• PSV (pressure safety relief)
• Release of HC (draining)	• Secondary protection from liquid overflow to the atmosphere should be provided by the ESSs.
• Residual strength of steel	• The residual strength of the steel may prevent release
6. Release due to external events	**Not analysed**
7. Release due to design related failures	**Not analysed**

11. Concluding remarks and further work

This report documents an attempt to develop a set of hydrocarbon release scenarios that can constitute the basis for analysis of platform specific frequencies of release of hydrocarbons in future risk analysis. The release scenarios may be used to identify and illustrate barriers aimed to prevent release of hydrocarbons. Further, the release scenarios may constitute the basis for analysis of the effect on the total risk of these barriers, and analysis of the effect of risk reducing measures (or risk increasing changes).

Each release scenario is described in terms of an initiating event (i.e., a “deviation”), the barrier functions aimed to prevent the initiating event from developing into a release, and how the barrier functions are realized in terms of barrier systems.

It has been attempted to use the safety barrier terminology suggested by a working group within the Together for Safety initiative (/21/). As a result, it has been distinguished between safety functions and safety barriers in the scenario descriptions. However, in most of the scenarios, it has been assumed that corrective actions, or at least risk compensating measures are implemented when deviations are detected. Thus, the barrier elements decision and action are not described. The validity of this assumption will be further discussed as part of the future work.

The presented scenarios do not cover absolutely all possible causes of release of hydrocarbons, but is considered to constitute a comprehensive and representative set of release scenarios. The initiating events cover the most frequent “causes” of hydrocarbon releases, and the scenarios include the most important barrier functions and barrier systems aimed to prevent releases.

The set of release scenarios will form the basis for the overall barrier model to be developed in the BORA project. This model will “link” the release scenarios with the “consequence barriers” by using the RiskSpectrum program.

Further work will focus on quantification of the scenarios presented in this report. A methodology for quantification is presented in (/22/), and challenges related to quantification are discussed in the same report.

Additional work will also be done in the BORA-project in order to further develop a framework for analysis of risk influencing factors (performance influencing factors or “ytelsespåvirkende forhold”) that influence the performance of the safety barriers. A draft framework is presented in (/22/).

12. Literature references

/1/ Vinnem, J.E, Aven T., Hauge S., Seljelid J., Veire G.; 2004. Integrated Barrier Analysis in Operational Risk Assessment in Offshore Petroleum Operations, Paper presented at PSAM/ESREL 2004.

/2/ Jan Erik Vinnem, Stein Hauge, Jorunn Seljelid, Snorre Sklet, Terje Aven, Operational risk analysis, Total analysis of physical and non-physical barriers, Plan for main project (pre-project report), Rev 4. Preventor Report No: 200254-03.

/3/ Hauge, S. og Sklet, S., "Modelling of the loss of containment barrier", SINTEF-memo 2003-12-15.

/4/ HSE Offshore hydrocarbon releases statistics and analysis 2002. HID Statistics Report HSR 2002 002, February 2003.

/5/ HSE report: OSD hydrocarbon release reduction campaign, report on the HC release incident investigation project – 1/4/2000 – 31/3/2001, Offshore Technology report 2001/055.

/6/ NPD "The risk level on the Norwegian Continental Shelf" 2002.

/7/ Jan Erik Vinnem, Presentasjon OLF-arbeidsseminar om gasslekkasjer, 17.09.2003.

/8/ Glittum E., Offshore lekkasjefrekvenser. Norsk Hydro Forskningssenteret Porsgrunn, Dok.nr. 01B_FP9, Dato 20.06.2001.

/9/ Glittum E., Analyse av lekkasjeårsaker på Norsk Hydros installasjoner. Norsk Hydro Forskningssenteret Porsgrunn, Dok.nr. 01D_CY1.iwp, Dato 20.12.2001.

/10/ DNV og RF, Årsaksanalyse av prosesslekkasjer, Forstudie Oljedirektoratet, Rapport nr DNV 2002-4019 og RF-2002/117, Rev. nr. 01, 30.04.2002.

/11/ Investigation reports on events reported in Synergi from Norsk Hydro.

/12/ Investigation reports on events reported in Synergi from Statoil.

/13/ Norsk Hydro, CD prepared for NPD Supervision "Technical and operational barriers", Rev 04, 02-03-2003.

/14/ ISO/DIS 10418:2001. Petroleum and natural gas industries – Offshore production installations – Analysis, design, installation and testing of basic surface process safety systems.

/15/ ISO/CD 14224 Rev 2, Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment. Date: 2004-05-13.

/16/ Norsk Hydro, Operational procedures for offshore platforms.

/17/ Øien K, Sklet S, Hauge S., Morgendagens HMS-analyser for vurdering av tekniske og organisatoriske endringer - Metode for barriereendringsanalyse (BEA). SINTEF-notat 16.01.2004.

/18/ Olson J, Chockie AD, Geisendorfer CL, Vallario RW, Mullen MF, 1988. Development of Programmatic Performance Indicators. NUREG/CR-5241, PNL-6680, BHARC-700/88/022, US Nuclear Regulatory Commission, Washington, D.C., USA.

/19/ Bellamy LJ, Papazoglou IA, Hale AR, Aneziris ON, Ale BJM, Morris MI & Oh JIH, 1999. I-RISK - Development of an Integrated Technical and Management Risk Control and Monitoring Methodology for Managing and Quantifying On-Site and Off-Site Risks. Main Report. Contract No: ENVA-CT96-0243, September 1999

/20/ OLF Recommended Guidelines for Common model for Work Permits (WP), No.: 088, Date effective: 05.11.03, www.samarbeidforsikkerhet.no.

/21/ Samarbeid for Sikkerhet, Arbeidsgruppe barrierer Rapport Fase 1 – forslag til begrep og definisjoner.

/22/ Aven T., Hauge S., Sklet S., and Vinnem J-E., Operational risk analysis, Total analysis of physical and non-physical barreirs H2.1 Methodology for Analysis of HOF Factors, Draft 0, Rev. 0, Preventor report no. 200254-04.

/23/ Davoudian K., Wu J-S & Apostolakis G. Incorporating organisational factors into risk assessment through the analysis of work processes. Reliability Engineering and System Safety, 1994, 45, 85-105

/24/ Papazoglou IA, Aneziris ON, Post JG, Ale BJM, 2003. Technical modeling in integrated risk assessment of chemical installations, Journal of Loss Prevention in the process industries, 16 (2003) 575 – 591, Elsevier.