BNG BODØ QRA

QRA for BNG LNG unit at Burøya (Bodø)

Barents Naturgass AS

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Objective:

The BNG plant in Bodø is planned to receive some modifications, defined by the addition of two evaporators in parallel with the already present evaporator E01A and E01B. The quantitative risk assessment of the installation needs therefore to be updated.

The assessment is carried out in accordance with the DSB regulation for LNG plants and the DNV GL guidelines.
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1 EXECUTIVE SUMMARY

Barents Naturgass (BNG) is planning to expand the LNG unit at Burøya (Bodø) with two additional evaporators in order to increase the production.

DNV GL was requested to perform a Quantitative Risk Analysis (QRA) of the qualified plant and to then compare the results against the acceptance criteria from Direktoratet for Samfunnssikkerhet og Beredskap (DSB).

The risk related to the operation and loading of the LNG unit at Burøya has been assessed using the DNV GL commercial software tool Safeti 8.11.

The risk is assessed as:

- The annual risk of 1E-05 covers 3rd party or public areas (part of Burøyveien);
- The annual risk of 1E-06 does not cover permanent housing; and
- The annual risk of 1E-07 does not include schools, hospitals or day care center.

Based on further analysis, BNG has assessed that gas dispersion over Burøyveien and resulting flash fire is unlikely. Based on their finding a new case (Case C) has been considered in the analysis, where the flash fire contribution to the risk is removed.

When removing the contribution from flash fires, the risk contours are smaller and the risk at the road is shown to be below 1E-05 per year.

This case is based on the findings from the analyses of BNG and these are out of the scope of this study. Given that the findings from BNG assessment are valid, the risk results from this case meet DSB acceptance criteria.

It is recommended to look into possible mitigating measures for limiting the spread of flammable gas clouds, in particular towards Burøyveien.
2 INTRODUCTION

2.1 Background
The BNG LNG unit in Burøya (Bodø, Norway) receives LNG from a truck tank and vaporizes it to the gas grid. Modification is planned at the installation. The change includes the addition of two evaporators in parallel to the ones already operating at the plant.

A quantitative risk assessment (QRA) of the resulting installation is therefore required.

2.2 Objective and scope
The objectives of the quantitative risk analysis conducted for the BNG Bodø installation are:

- Hazard identification;
- Evaluation of likelihood and consequences of hazardous events; and
- Risk evaluation and assessment.

The scope is to assess whether the suggested modification is acceptable from a safety point of view during the operational phase and to propose risk reducing measure when necessary.

2.3 Limitations of the scope
The scope of the risk assessment is limited to the operational phase.

2.4 Abbreviations and acronyms
BNG  Barents Naturgass AS
DSB  Direktoratet for Samfunnssikkerhet og Beredskap
LNG  Liquefied Natural Gas
NG  Natural Gas grid
PBU  Pressure Build-up Unit
QRA  Quantitative Risk Assessment
3 DESCRIPTION OF THE INSTALLATION

3.1 General
The installation is located at Burøya in Bodø municipality in North Norway. Figure 3-1 shows a view of the facility.

![Figure 3-1 BNG Bodø installation view](source: BNG, ref. /3/)

The installation is designed to receive LNG from an LNG truck. The tank is loaded by truck, according to the frequency described in 3.3 for low and high season. The LNG is then vaporized and sent to the NG grid.

The installation consists of the following main equipment:
- Main LNG tank (capacity 127 m³);
- LNG product vaporizers (capacity 25 MW);
- Stainless steel piping without insulation;
- Electrical trim-heater;
- Pressure reduction station and odorizer injector;
- Gas pipeline (underground and subsea).

Detailed information about process conditions are provided in the assumption report.

3.2 Description of the modification planned at the installation
The modification of the LNG unit at Bodo includes the addition of two new product vaporizers in parallel with the existing ones E01A/B. The planned expansion is shown in Figure 3.2.
The update will include two new ambient air vaporizers, four new manual valves for isolation, two new manual valves for draining and three new safety valves (ref. /5/).

3.3 Operational phases

Two periods are considered for the industrial site. The first is defined as high season and lasts from October to April. The loading of the tank is daily during this time. The second period is defined as low season and lasts from May to September. The loading is weekly in that case.

Detailed information about high and low seasons is provided in the assumption register of the study.

3.4 Safety systems

3.4.1 ESD system

The BNG Bodø installation is equipped with ESD system that can be triggered at different locations of the unit, both inside the tank area and in the local control room.

The isolation can be activated both manually and by gas detection.

The ESD system, once activated, cause the immediate closure of all the automated valves on the installation. Three push-buttons are distributed in the area, one at the tank and two outside and inside the control room respectively.

The LNG truck is equipped with its own ESD system.
3.4.2 Detection system

The LNG tank area is equipped with two gas detectors, a flame detector, and a temperature sensor (detecting liquid releases).

The local control room has a gas detector as well.
4 RISK TERM AND CONCEPTS

4.1 Risk methodology
The assessment has been carried out following the QRA guidelines recently published by DSB (ref. /1/). The approach goes through 4 phases: Hazard Identification, Frequency Assessment, Consequences and Risks assessment, Evaluation of mitigating measures.

4.2 Risk tolerance criteria
DSB safety criteria (ref. /2//1/) are applied to assess whether or not the risk levels arising from the operation are acceptable, and whether or not any additional safeguards are required to reduce the risk levels to as low as reasonably practicable.

DSB's criteria are summarized in the table below:

<table>
<thead>
<tr>
<th>Hazardous zones</th>
<th>Individual Risk</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner zone</td>
<td>1E-05 per year</td>
<td>This is basically the business's own area. In addition, for example, LNF area can be included in the inner zone. Only short-term passage for third parties.</td>
</tr>
<tr>
<td>Middle zone</td>
<td>1E-06 per year</td>
<td>Public road, rail, dock and similar. Permanent industry and office can also be found here. In this zone, there should not be accommodation or housing. Scattered housing can be accepted in some cases.</td>
</tr>
<tr>
<td>Outer zone</td>
<td>1E-07 per year</td>
<td>Areas regulated for residential purposes and other uses of the general population can be included in the outer zone, including shops and smaller accommodations.</td>
</tr>
<tr>
<td>Outside Outer Zone</td>
<td>Not defined</td>
<td>Schools, kindergarten, nursing homes, hospitals and similar institutions, shopping centres, hotels or large public arenas must normally be placed outside the outer zone.</td>
</tr>
</tbody>
</table>

Figure 4.1 DSB criteria for hazardous zones.
5 HAZARD IDENTIFICATION

5.1 Hazard identification
The hazard identification has been carried out based on the experience of DNV GL. The following scenarios have been identified:

- Loss of containment from the equipment (valves and piping) at the tank area;
- Loss of containment from the hose at the tank area; and
- Loss of containment from the LNG loading truck.

The segments at the Bodø LNG unit are pressurized and filled with LNG all the time (except the loading hose and the tank inlet segment). Therefore, loss of containment from any equipment connected to the tank or other equipment is assessed as a credible scenario.

5.2 Hazards related to LNG
Due to its properties, LNG will result in different type of consequence, if spilled and in contact with personnel or materials. This paragraph describes what can happen if LNG is released in the atmosphere and the possible resulting effects.

If a small quantity of LNG is released in the atmosphere, it will evaporate. With an extremely large quantity of LNG, insufficient heat can be transferred so that a pool may form, which will then evaporate. Depending on the size of the outflow and the local conditions (e.g. presence of ignition sources), the following effects may occur:

- Fire and explosion;
- Rapid Phase Transition;
- Cryogenic exposure;
- Suffocation; and
- Greenhouse gas effects.

5.2.1 Fire and explosion
5.2.1.1 Flash fire
A flash fire is a non-explosive combustion of a flammable vapour cloud. In general, a flash fire occurs when a vapour cloud encounters a source of ignition (such as a naked flame, combustion engine, sparks etc.). This is in the case of delayed ignition. The vapour cloud is often ignited on the edge (where the concentration is lower), after which the fire spreads to all the flammable mass and then continues burning up to the UFL until all the mass is gone. Different flame fronts can exist, which might propagate back to the LNG pool (if any), resulting in a pool fire.

This hazard is included in the analysis.

5.2.1.2 Jet fire
A jet fire usually occurs in the event when LNG is immediately ignited when it is released in a continuous stream (i.e. immediate ignition, no puddle or vapour cloud is initially formed). However, residual jet fires
are also possible in the case of delayed ignition of a flammable cloud where the flame front travels all the way back to the source of the release.

This hazard is included in the analysis.

5.2.1.3 Pool fire
A pool fire occurs when a pool of LNG (which occurs with large releases) is ignited or when the flammable vapour cloud is ignited above the pool. In the latter case, the flash fire will ignite the pool. LNG pool fires cause a significant amount of thermal radiation (due to the luminous flame), which decreases as a function of distance from the pool fire.

This hazard is included in the analysis.

5.2.1.4 Semi-confined and confined vapour cloud explosions
A vapour cloud explosion can occur when a large quantity of gas is ignited (delayed) in a confined or semi-confined space (e.g. congested area).

This hazard is included in the analysis.

5.2.2 Rapid Phase Transition (RPT)
This is an extremely rapid physical phase transition resulting from the temperature difference from liquid LNG to methane vapour, especially as a consequence of immersion in water. There is no combustion with RPT. The pressure wave that is created by small quantities of LNG vaporising instantaneously when overheating occurs due to mixing with water, will propagate with the speed of sound and deteriorate like any other pressure pulse. Usually no specific modelling is carried out for RPT, because it is improbable that the effects of RPT make a significant contribution to the total danger area of a large leak that has already taken place.

RPT is usually relevant for leaks over water and therefore is not considered in the analysis.

5.2.3 Cryogenic exposure
If LNG is stored under atmospheric conditions, the temperature will be -162 °C. Due to the cryogenic conditions, there is a danger of frostbite symptoms on exposure to persons, structural materials (steel), components, instrumentation and cabling because of the low temperature.

Exposure of persons causes frost burn. Exposure of carbon steel causes brittleness which can result in structural failure.

The analysis does not cover cryogenic risk as it is considered to have negligible contribution to 3rd party risk.

5.2.4 Suffocation
LNG is not carcinogenic or toxic. LNG and the resulting vapour clouds have a suffocating effect because air is rarefied or expelled which in the case of long-term exposure can result in death by suffocation. Considering that the pure gas is colourless and odourless, this must be taken account of primarily in confined spaces. For large releases, persons in the immediate vicinity may suffer from low oxygen concentrations (<6 vol%). Concentrations of 50% by volume (methane in air) will cause obvious suffocation symptoms like difficulties in breathing and rapid breathing at the same time as the ability to respond deteriorates and mussel coordination weakens.

Suffocation is not assessed in the analysis as the area is open.
5.2.5 Greenhouse effects

Unburned natural gas is a greenhouse gas and if LNG is released, it contributes to global warming and climate change.

The analysis does not cover greenhouse effect as it is an environmental hazard.
6 FREQUENCY ASSESSMENT

6.1 Pipeline frequency assessment

The buried/underground pipeline frequency assessment has been carried out according to DNV GL Recommended failure rates for pipeline (ref. /5/).

The release frequency for the pipeline, $F_{\text{release}}$, is calculated according to the following equation:

$$F_{\text{release}} = F_{\text{km}} \cdot L_{\text{pipeline}} + F_{\text{Score}} \cdot S_{\text{pipeline}}$$

Where: $F_{\text{km}}$ is the length dependent failure, $L_{\text{pipeline}}$ is the length of the pipeline (in km), $F_{\text{Score}}$ is the length independent failure and $S_{\text{pipeline}}$ is the pipeline score, representing the characteristic of the pipeline.

The recommended value for $F_{\text{km}}$ is $1.7\times10^5$ per km year for pipelines with diameter lower or equal to 24”.

For the same pipeline, $F_{\text{Score}}$ is set as $7.1\times10^{-5}$ per score grade year.

$S_{\text{pipeline}}$ is calculated as the sum of 5 different scores, defined as:

- Loads from trawl boards;
- Anchor interaction, ship loss;
- Corrosion, internal/external;
- Open spans; and
- Buckling.

The scores vary from 0 to 10, with the following implication:

- 0: nor or little importance;
- 1: some importance;
- 3: Medium importance; and
- 10: significant importance.

Table 6-1 summarized the value adopted in this analysis for the buried and subsea pipeline. The frequency (/year) adopted for the gas pipeline is shown in Table 6-2 in the next section.

Table 6-1 Score assessment for buried and subsea pipeline

<table>
<thead>
<tr>
<th></th>
<th>Buried pipeline</th>
<th>Subsea pipeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loads from trawls and boards</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Anchor interaction/ship loss</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Corrosion, internal/external</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Open spans</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Buckling</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$S_{\text{pipeline}}$</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
6.2 Release frequencies

An overview of the estimated leak frequencies per ESD-segment and leak category is provided in Table 6-2 and Figure 6.1. Figure 6.2 represents the leak contribution per leak size.

From Table 6-2 the total leak frequency of the plant is 4.34E-02. The main contributors to the leak frequency are, in contributing order, the tank (ID.2) and the evaporators (ID. 4 and 6) (see also Figure 6.1). The three segments contribute to the total leak frequency for 28, 25, 20 % respectively (see Table 6-2).

From Figure 6.2, the leak size that mostly contributes to the releases at the plant is the small one (89%). Medium releases contribute for 8% while the large ones for 3%.

Note that there is some uncertainty related to the leak frequency assessment of the new evaporators since detailed drawings were not available at the time of the study. However, the parts count has been carried out based on the information for the existing evaporators which have a similar design and therefore assessed to be representative. The input has been provided by BNG (ref. /5/).

### Table 6-2 Leak frequency per ESD-segment and leak category

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
<th>Total</th>
<th>Contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Loading hose</td>
<td>6.36E-05</td>
<td>0.00E+00</td>
<td>1.59E-05</td>
<td>7.95E-05</td>
<td>0.2%</td>
</tr>
<tr>
<td>1</td>
<td>Inlet piping</td>
<td>1.49E-04</td>
<td>1.87E-06</td>
<td>0.00E+00</td>
<td>1.51E-04</td>
<td>0.4%</td>
</tr>
<tr>
<td>2</td>
<td>LNG tank</td>
<td>9.57E-03</td>
<td>1.22E-03</td>
<td>9.54E-06</td>
<td>1.08E-02</td>
<td>28.3%</td>
</tr>
<tr>
<td>3</td>
<td>To evaporators</td>
<td>3.99E-03</td>
<td>1.34E-04</td>
<td>0.00E+00</td>
<td>4.12E-03</td>
<td>10.8%</td>
</tr>
<tr>
<td>4</td>
<td>Evaporators</td>
<td>8.10E-03</td>
<td>1.03E-03</td>
<td>3.87E-04</td>
<td>9.52E-03</td>
<td>24.9%</td>
</tr>
<tr>
<td>5</td>
<td>To NG pipeline</td>
<td>3.37E-03</td>
<td>3.45E-04</td>
<td>4.56E-05</td>
<td>3.76E-03</td>
<td>9.8%</td>
</tr>
<tr>
<td>6</td>
<td>New evaporators</td>
<td>6.76E-03</td>
<td>6.74E-04</td>
<td>2.65E-04</td>
<td>7.70E-03</td>
<td>20.1%</td>
</tr>
<tr>
<td>7</td>
<td>PBU unit</td>
<td>1.55E-03</td>
<td>1.61E-04</td>
<td>0.00E+00</td>
<td>1.71E-03</td>
<td>4.5%</td>
</tr>
<tr>
<td>8</td>
<td>Gas underground pipeline (before subsea)</td>
<td>1.19E-04</td>
<td>7.54E-06</td>
<td>2.41E-05</td>
<td>1.51E-04</td>
<td>0.4%</td>
</tr>
<tr>
<td>9</td>
<td>Gas subsea pipeline</td>
<td>1.18E-04</td>
<td>7.48E-06</td>
<td>2.39E-05</td>
<td>1.50E-04</td>
<td>0.4%</td>
</tr>
<tr>
<td>10</td>
<td>Gas underground pipeline (after subsea)</td>
<td>5.82E-05</td>
<td>3.69E-06</td>
<td>1.18E-05</td>
<td>7.37E-05</td>
<td>0.2%</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>3.39E-02</strong></td>
<td><strong>3.58E-03</strong></td>
<td><strong>7.83E-04</strong></td>
<td><strong>3.82E-02</strong></td>
<td></td>
</tr>
</tbody>
</table>
Figure 6.1 Leak frequency contribution per ESD-segment and leak size

Figure 6.2 Leak contribution per leak size
7 RISK RESULTS

A total of three cases have been considered for the Bodø LNG unit.

Initially two cases have been analysed, respectively Case A and Case B, differing for the modelling of delayed ignition, as described in Appendix A, assumption 3.5.

A further analysis, respectively Case C, has been requested by BNG later based on further investigation. For this case, the modelling of ignition has been carried out as per Case B but the contribution of flash fires to the risk has been removed.

BNG has performed additional CFD simulations to further analyse gas dispersion and consequent flash fires on Burøyveien and assessed this to be unlikely (ref. /7/). These further analyses have been run by BNG and are not part of DNV GL assessment. Case C presents the risk contours for the LNG unit without the contribution from flash fires.

7.1 Risk results for Case A

In Case A, the real ignition sources in the surrounding of the LNG unit are considered. They are described in Appendix A (see Assumption 3.5, 3.6 and 3.8).

Figure 7.1 shows the location specific individual risk in the form of iso-risk contours corresponding to the frequency (per year) at which a fatality can be expected should somebody be present continuously at a particular location.

Risk contours are used in risk acceptance criteria (see Chapter 4.2). Risk level of 1E-05 is limited to a small area in the LNG unit, the risk contour of 1E-06 cover the installation area but not public areas, although it is very close to Burøyveien. Risk level 1E-07 does not cover any area with particularly sensitive population, as school or hospital, but it covers part of the area where the commercial buildings are (even though, a very limited part of that area).

The contribution of the buried and subsea gas pipelines is not appreciable.
7.2 Risk results for Case B

In Case B, the delayed ignition is set as unitary. In this case, every release from the unit that does not immediately ignite, will ignite when at its maximum dispersion (i.e. at a concentration equal to the LFL).

This case is described in Appendix A (see assumption 3.5).

Figure 7.2 shows the location specific individual risk in the form of iso-risk contours corresponding to the frequency (per year) at which a fatality can be expected should somebody be present continuously at a particular location.

When delayed ignition is set as one, the risk contours are bigger than for Case A. In this case, every release, not ignited immediately, has time to spread in the area before being ignited. As a result, risk level 1E-05 covers part of Burøyveien, and, generally, the risk contours related to 1E-06 and 1E-07 cover a wider area.
7.3 Risk Results for the case C (no flash fire effect)

In this chapter, the iso-risk contours without the contribution of the flash-fire effect (case C) are presented. This case is built on the model from Case B, i.e. the delayed ignition for the release scenarios is set as 1.

Figure 7.3 shows the location specific individual risk in the form of iso-risk contours corresponding to the frequency (per year) at which a fatality can be expected should someone be present continuously at a particular location for Case C (no flash fire effects).

Figure 7.4 shows the comparison for the risk level 1E-05 /average year for Case B (in blue) and Case C (in purple).

Not accounting for flash fire effects results in smaller risk contours than for Case B. Specifically, for Case C, the risk level at the road is below 1E-05 /average year risk.

Note that the risk contours should not be used as is, for other purposes than evaluating the risk at Bursøyveien, as flash fire is a plausible effect resulting from a leak at the plant, but detailed analysis ordered by BNG shows that such outcome should not expose the road.
Figure 7.3 Iso-risk contour for the LNG unit at Burøya for Case C (No flash fire effect)

Figure 7.4 Comparison of iso-risk contour 1E-05 for case B (blue) and case C (purple)
8 CONSEQUENCE ASSESSMENT

Risk ranking points (RRPs) are introduced in the model as shown in Figure 8.1. RRPs represent locations where the risk is measured in detail. They are used in order to assess the scenarios that have the major contribution to the risk and to assess the type of outcome (fire, explosion) that can develop in a specific location.

![Figure 8.1 Risk Ranking Points adopted in the study](image)

Table 8-1 lists the release scenarios that give the main contribution to the risk at Burøyveien, as measured at RRP A, for Case A. The other release scenarios not listed in the table have a contribution to the risk of 2% or lower.

### Table 8-1 Main contributors to risk at Burøyveien (RRP A) for Case A

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Node</th>
<th>Phase</th>
<th>Size</th>
<th>ESD</th>
<th>Total risk (/year)</th>
<th>Contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01-A</td>
<td>2 – Tank</td>
<td>Liquid</td>
<td>Large</td>
<td>Yes</td>
<td>3.63E-07</td>
<td>51 %</td>
</tr>
<tr>
<td>02-A</td>
<td>0 – Loading hose</td>
<td>Liquid</td>
<td>Large (Rupture)</td>
<td>Yes</td>
<td>1.14E-07</td>
<td>16 %</td>
</tr>
<tr>
<td>03-A</td>
<td>2 – Tank</td>
<td>Liquid</td>
<td>Medium</td>
<td>Yes</td>
<td>8.71E-08</td>
<td>12 %</td>
</tr>
<tr>
<td>04-A</td>
<td>0 – Loading hose</td>
<td>Liquid</td>
<td>Large (Rupture)</td>
<td>No</td>
<td>4.79E-08</td>
<td>7 %</td>
</tr>
<tr>
<td>05-A</td>
<td>2 – Tank</td>
<td>Liquid</td>
<td>Large</td>
<td>No</td>
<td>4.04E-08</td>
<td>6 %</td>
</tr>
<tr>
<td>06-A</td>
<td>1 – Inlet piping</td>
<td>Liquid</td>
<td>Medium</td>
<td>ESD</td>
<td>2.49E-08</td>
<td>3.5 %</td>
</tr>
</tbody>
</table>

Scenario 01-A (tank liquid release, large hole size category with successful ESD activation) has a contribution on the total risk at Burøyveien of circa 51%.

Table 8-2 lists the release scenarios that give the main contribution to the risk at Burøyveien, as measured at RRP A, for Case B. The other release scenarios not listed in the table have a contribution to the risk of 2% or lower.
### Table 8-2 Main contributors to risk at Burøyveien (RRP A) for Case B

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Node</th>
<th>Phase</th>
<th>Size</th>
<th>ESD</th>
<th>Total risk (/year)</th>
<th>Contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01-B</td>
<td>2 – Tank</td>
<td>Liquid</td>
<td>Medium</td>
<td>Yes</td>
<td>1.4E-05</td>
<td>27.5 %</td>
</tr>
<tr>
<td>02-B</td>
<td>7 – PBU unit</td>
<td>Liquid</td>
<td>Medium</td>
<td>Yes</td>
<td>1.3E-05</td>
<td>25.6 %</td>
</tr>
<tr>
<td>03-B</td>
<td>3 – To Evaporators</td>
<td>Liquid</td>
<td>Medium</td>
<td>Yes</td>
<td>1.1E-05</td>
<td>21.3 %</td>
</tr>
<tr>
<td>04-B</td>
<td>0 – Loading hose</td>
<td>Liquid</td>
<td>Large (Rupture)</td>
<td>Yes</td>
<td>4.9E-06</td>
<td>9.4 %</td>
</tr>
<tr>
<td>05-B</td>
<td>2 – Tank</td>
<td>Liquid</td>
<td>Large</td>
<td>Yes</td>
<td>2.68E-06</td>
<td>5.1 %</td>
</tr>
<tr>
<td>06-B</td>
<td>3 – To Evaporators</td>
<td>Liquid</td>
<td>Medium</td>
<td>No</td>
<td>1.7E-06</td>
<td>3.2 %</td>
</tr>
<tr>
<td>07-B</td>
<td>2 – Tank</td>
<td>Liquid</td>
<td>Medium</td>
<td>No</td>
<td>1.6E-06</td>
<td>3 %</td>
</tr>
<tr>
<td>08-B</td>
<td>7 – PBU unit</td>
<td>Liquid</td>
<td>Medium</td>
<td>Yes</td>
<td>1.5E-06</td>
<td>2.9 %</td>
</tr>
</tbody>
</table>

Scenario 01-B (tank liquid release, medium hole size category with successful ESD activation) has a contribution on the total risk at Burøyveien of circa 27.5 %.

For case A, the consequence that has the main impact on the risk is jet fire. In case B, the main contributors to the risk are flash fires, pool fire and jet fire with resulting pool fire.

When removing the flash fire effects, the main contributors at Burøyveien are as per list in Table 8-3.

### Table 8-3 Main contributors to risk at Burøyveien (RRP A) for Case C (no flash fire effect)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Node</th>
<th>Phase</th>
<th>Size</th>
<th>ESD</th>
<th>Total risk (/year)</th>
<th>Contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01-C</td>
<td>2 – Tank</td>
<td>Liquid</td>
<td>Large</td>
<td>Yes</td>
<td>1.6E-06</td>
<td>74.7 %</td>
</tr>
<tr>
<td>02-C</td>
<td>0 – Loading hose</td>
<td>Liquid</td>
<td>Large (Rupture)</td>
<td>Yes</td>
<td>2.8E-07</td>
<td>13.2 %</td>
</tr>
<tr>
<td>03-C</td>
<td>2 – Tank</td>
<td>Liquid</td>
<td>Large</td>
<td>No</td>
<td>1.78E-07</td>
<td>8.3 %</td>
</tr>
<tr>
<td>04-C</td>
<td>0 – Loading hose</td>
<td>Liquid</td>
<td>Large (Rupture)</td>
<td>No</td>
<td>3.57E-08</td>
<td>1.7 %</td>
</tr>
</tbody>
</table>

The cloud dispersion for large release from the LNG tank with successful ESD activation (scenario 01-A) is shown in Figure 8.2 and Figure 8.3.

Figure 8.2 shows the side view of the cloud (cloud height and cloud distance) referring to the LFL concentration and three weather categories. Two different time steps are represented. Panel A refers to
the start of the release. The cloud within the flammability limit touches a distance of about 19 m
downwind. A liquid pool is also created at a downwind distance from the tank of about 8 m. Panel B
shows the maximum impact distance downwind of the cloud within flammable composition. Its maximum
is about 90 m for stable and low wind weather conditions. In this case, the cloud will be subject to lower
turbulence effects and it will keep its concentration within the flammability limit for longer distances. See
Chapter 9.4 for more detail on how weather conditions affect the cloud dispersion.

Figure 8.3 shows the cloud footprint (cloud width and cloud distance) referring to the LFL concentration
and three different weather categories. The maximum extension of the cloud in its width is about 40 m.

Figure 8.2 Cloud side view for large liquid release from the LNG tank with successful
activation of the ESD. Panel A: start of release; panel B: maximum impact distance downwind.
Figure 8.3 Cloud footprint for large liquid release from the LNG tank with successful activation of the ESD. Panel A: start of release; panel B: maximum width.

The cloud dispersion for medium release from the LNG tank with successful ESD activation (scenario 01-B) is shown in Figure 8.4 and Figure 8.5.

Figure 8.4 shows the side view of the cloud (cloud height and cloud distance) referring to the LFL concentration and three weather categories. Two different time steps are represented. Panel A refers to the start of the release. The cloud within the flammability limit touches a distance of about 13.5 m downwind. A liquid pool is also created at a downwind distance from the tank of about 8 m. Panel B shows the maximum impact distance downwind of the cloud within flammable composition. Its maximum is about 55 m for stable and low wind weather conditions. In this case, the cloud will be subject to lower turbulence effects and it will keep its concentration within the flammability limit for longer distances. See Chapter 9.4 for more detail on how weather conditions affect the cloud dispersion.

Figure 8.5 shows the cloud footprint (cloud width and cloud distance) referring to the LFL concentration and three different weather categories. The maximum extension of the cloud in its width is about 15 m.
Figure 8.4 Cloud side view for medium liquid release from the LNG tank with successful activation of the ESD. Panel A: start of release; panel B: maximum impact distance downwind.
Figure 8.5 Cloud footprint for medium liquid release from the LNG tank with successful activation of the ESD. Panel A: start of release; panel B: maximum width.

The effects of the failure of the gas pipeline when subsea have been assessed using PlumePro. Given the flowrate in the pipeline (considered, conservatively, when at high season, i.e. 2500 Nm3/h), the amount of gas that gets to the sea surface is not enough to produce any appreciable consequence.

Figure 8.6 presents the cloud footprint at three different time-steps for the rupture of the subsea pipeline.
Figure 8.6 Cloud footprint for the rupture of the subsea pipeline. Panel A) at $t=0$ s; Panel B) at $t=37$ s; Panel C) at $t=73$ s (just right before the pool is completely vaporized).

The rupture of the buried pipeline might result in flash-fire. Figure 8.7 shows the maximum extension of a flash-fire resulting from the rupture of the buried pipeline. The resulting flash-fire has a maximum radius of about 2 m.
Figure 8.7 Flash-fire envelope for the rupture of the buried pipeline.
9 UNCERTAINTY

9.1 Leak frequencies and representative hole sizes

The leak frequency and the hole size category distribution represent the foundation of risk analysis, and the risk is directly proportional to leak frequency.

Uncertainties are related to both the total leak frequency and the categorization between small, medium and large leaks. The effect on risk level from total leak frequency is however considered to be subordinate to the effect of distribution between leak sizes. Furthermore, the leak frequency model used for equipment and piping is based on an offshore method and therefore it might not describe satisfactorily the equipment onshore.

The parts count that is applied for the frequency estimation is based on coarse input but assumed to be a reasonable estimate of the number of equipment. The uncertainties lie in the use of generic leak data and in neglecting the technical condition of the equipment on the plant during the estimation of the frequency.

The release frequency associated with the new evaporators is evaluated by assuming a reasonable equipment counting. No detailed P&IDs were available at the moment the analysis was carried out. This represents an uncertainty of the model.

9.2 Ignition probability

The results from the risk analysis are highly dependent on the ignition probabilities. The ignition probability affects the fire frequency and, hence the risk. Recognized ignition probability models are used as basis for the risk modelling. These models are uncertain due to the limited statistical data connected to ignited HC releases and the unknowns related to the actual mechanism causing them. Therefore, although the choice of recognized models, the analysis suffers relatively high uncertainty connected to the ignition probabilities.

However, this uncertainty is addressed by presenting the results of Case B which uses the conservative approach recommended by DSB Guideline (Ref. /1/) with a delayed ignition probability of 1.

9.3 Safeti 8.11

The risk is calculated in Safeti 8.11 using the impact models incorporated in PHAST 8.11. Each consequence model has its limitations and strives to describe the reality as best as possible with regards to some conservatism to handle the uncertainties in modelling.

The main limitation of the impact models (such as dispersion, jet fires, pool fire, explosion) in PHAST is that it does not accurately take into account physical obstacles or barriers (such as a the hill behind the tank or the hill between the tank and Bursøyveien) that can 'block' fire effects or prevent the spread of a flammable cloud.

A physical obstacle that is as large as the hills around the LNG tank influences also the incoming wind, generating increased turbulence. This effect cannot accurately be modelled in Safeti and is only considered in a limited manner by modifying the roughness of the surface (see the Assumption Report for the value adopted in the study).

Possible vortexes or recycling of gas dispersion in the cavity are also not considered. It is expected that this will result in more dilution if considered, resulting in less distances to LFL.
The risk contours extending over the hill should therefore not be considered realistic as a gas cloud would most probably not cover the top of the hill and rather disperse upward or around the hill. Given the wind rose, which shows a strongly dominant wind from East (~40% of the time), the impact of the hill on the risk contours should be limited (except on the hill itself where the risk contours should be shorter).

9.4 Weather data

The windrose and weather conditions used in this assessment are based on data from the Meteorological Institute and is considered to be robust. Unfortunately, weather stations are technically not close to the evaluated place.

The location of the tank is quite unique because of the hill on the back side and on the road side.

It is therefore expected that wind direction and velocity will be a bit different from the values obtained from the Meteorological Institute.
10 CONCLUSION AND RECOMMENDATIONS

DNV GL has performed the QRA for the LNG unit at Burøya in accordance with DSB requirements. The risk is calculated using Safeti, DNV GL’s commercial software tool. The risk levels are compared with DSB acceptance risk criteria.

From the analysis it has been concluded that:

- The annual risk of 1E-05 covers 3rd party or public areas (in particular, part of Burøyveien);
- The annual risk of 1E-06 does not cover permanent housing; and
- The annual risk of 1E-07 does not include schools, hospitals or day care center.

The risk contours corresponding to 1E-05 do not meet DSB criteria.

Based on further analysis, BNG has assessed that gas dispersion over Burøyveien and resulting flash fire is unlikely. Based on their finding a new case (Case C) has been considered in the analysis, where the flash fire contribution to the risk is removed.

When removing the contribution from flash fires, the risk contours are smaller and the risk at the road is shown to be below 1E-05 per year.

This case is based on the findings from the analyses of BNG and these are out of the scope of this study. Given that the findings from BNG assessment are valid, the risk results from this case meet DSB acceptance criteria.

It is recommended to look into possible mitigating measures for the spread of flammable gas clouds, in particular towards Burøyveien.
11 REFERENCES

/1/ DSB (2011). Temaveiledning om omtapping av farlig stoff. Tilgjengelig fra:

/2/ DSB (2013). Sikkerheten rundt anlegg som håndterer brannfarlige, reaksjonsfarlige, trykksatte og eksplosjonsfarlige stoffer. Kriterier for akseptabel risiko. Tilgjengelig fra:

/3/ Email from Thomas Øien on 1st June 2018, “QRA for LNG unit på Burøya, Bodø”.

/4/ Email from Thomas Øien on 17th August 2018, “Questions for BNG”.


/6/ Email from Stig Ove Hjelmevoll on 29th of May 2019.

About DNV GL
Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil & gas and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our professionals are dedicated to helping our customers make the world safer, smarter and greener.
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1 INTRODUCTION

This document presents the assumptions applied for the QRA of Bodo LNG industrial installation.

These assumptions are the foundations of the QRA and impact significantly the end results. Any changes to these assumptions will consequently invalidate the risk picture.

The assumptions were developed in collaboration with and approved by Barents Naturgass (BNG) personnel.

The assumptions are presented in three distinctive sections:

- **Analytical assumptions**
  Analytical assumptions are the bases of the analytical model developed in Safeti 8.1. It should be noted that some of the assumptions are simplified because of the limitations of the software or to help with the modelling of complex scenarios.

- **Technical assumptions**
  Technical assumptions are there to represent the technical aspect of the process equipment considered in the QRA

- **Operational assumptions**
  Operational assumptions are directly linked to the operations of the loading installation.
2 OVERVIEW OF ASSUMPTIONS

The assumptions described in the following of this report are presented in Table 2-1.

Table 2-1 Overview of Assumptions

<table>
<thead>
<tr>
<th>No.</th>
<th>Category</th>
<th>Description</th>
<th>Rev.</th>
<th>Comment</th>
</tr>
</thead>
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<tr>
<td>3.1</td>
<td>Analytical</td>
<td>Impact criteria</td>
<td>1</td>
<td>Re-written</td>
</tr>
<tr>
<td>3.2</td>
<td>Analytical</td>
<td>Size, frequency and location of leaks</td>
<td>1</td>
<td>Re-written and reviewed</td>
</tr>
<tr>
<td>3.3</td>
<td>Analytical</td>
<td>Leak duration and leak rates</td>
<td>0</td>
<td>No changes</td>
</tr>
<tr>
<td>3.4</td>
<td>Analytical</td>
<td>Leak direction</td>
<td>0</td>
<td>No changes</td>
</tr>
<tr>
<td>3.5</td>
<td>Analytical</td>
<td>Immediate and delayed ignition</td>
<td>1</td>
<td>Updated of delayed ignition probability. Description of ignition values adopted for Case A and Case B of the study</td>
</tr>
<tr>
<td>3.6</td>
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<td>0</td>
<td>No changes</td>
</tr>
<tr>
<td>3.7</td>
<td>Analytical</td>
<td>Obstructed areas</td>
<td>0</td>
<td>No changes</td>
</tr>
<tr>
<td>3.8</td>
<td>Analytical</td>
<td>Traffic</td>
<td>0</td>
<td>No changes</td>
</tr>
<tr>
<td>3.9</td>
<td>Analytical</td>
<td>ESD philosophy</td>
<td>0</td>
<td>No changes</td>
</tr>
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<td>3.10</td>
<td>Analytical</td>
<td>ESD time</td>
<td>0</td>
<td>No changes</td>
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<td>3.11</td>
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<td>Probability of failure of the ESD system</td>
<td>1</td>
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</tr>
<tr>
<td>3.12</td>
<td>Analytical</td>
<td>Meteorological data and windrose</td>
<td>0</td>
<td>No changes</td>
</tr>
<tr>
<td>4.1</td>
<td>Technical</td>
<td>Impounding areas</td>
<td>0</td>
<td>No changes</td>
</tr>
<tr>
<td>4.2</td>
<td>Technical</td>
<td>Segmentation of the LNG system</td>
<td>1</td>
<td>Update of Table 4-1 to include the gas pipeline segment</td>
</tr>
<tr>
<td>5.1</td>
<td>Operational</td>
<td>Operation phases</td>
<td>0</td>
<td>No changes</td>
</tr>
<tr>
<td>5.2</td>
<td>Operational</td>
<td>Manning level and distribution</td>
<td>0</td>
<td>No changes</td>
</tr>
</tbody>
</table>
ANALYTICAL ASSUMPTIONS

3.1 Impact criteria

ASSUMPTIONS REGISTER

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<thead>
<tr>
<th>Assumption No.:</th>
<th>Date: 2019-05-16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject:</td>
<td>Impact criteria on buildings and equipment</td>
</tr>
<tr>
<td>Category:</td>
<td>Analytical assumption</td>
</tr>
</tbody>
</table>

Specifications:

The overpressure and radiation outdoor vulnerability in the proximity of the LNG unit are set using the probit model.

The probit equation for death due to explosion is expressed as:

\[ Pr = A + B \ln(P^N) \]

Where \( Pr \) is the probit value corresponding to the probability of death due to overpressure exposure and \( P \) is the peak overpressure (Pa).

Table 3-1 shows the parameters adopted for the probit equation used to assess the outdoor vulnerability due to explosion.

Table 3-1 Parameters used for the explosion probit equation (outdoor vulnerability)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-16.7319</td>
</tr>
<tr>
<td>B</td>
<td>2.44</td>
</tr>
<tr>
<td>N</td>
<td>1</td>
</tr>
</tbody>
</table>

The probit equation for death due to heat radiation is expressed as:

\[ Pr = A + B \ln(Q^N x t) \]

Where \( Pr \) is the probit value corresponding to the probability of death due to fire exposure, \( Q \) is the heat radiation (W/m²) and \( t \) is the exposure time (s).

Table 3-2 shows the parameters as set for the radiation probit equation. The probit equation is used to assess the outdoor vulnerability for fireball, jet-fire and pool-fire scenarios.

Table 3-2 Parameters used for the radiation probit model (outdoor vulnerability)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-36.38</td>
</tr>
<tr>
<td>B</td>
<td>2.56</td>
</tr>
<tr>
<td>N</td>
<td>1.3333</td>
</tr>
</tbody>
</table>
For flash fire scenarios, a fatality rate equal to 1 is assumed within the LFL concentration. The LFL fraction to finish is set as 100%.

**Implication of assumption:**

These criteria impact the on the risk results and the number of fatalities of population considered in the vicinity.

**References for this assumption:**


<table>
<thead>
<tr>
<th>Prepared by:</th>
<th>Sign: MARBUC</th>
<th>Date: 2019-05-16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marta Bucelli</td>
<td></td>
<td></td>
</tr>
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<table>
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<th>Sign: OBAL</th>
<th>Date: 2019-05-16</th>
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<tbody>
<tr>
<td>Olivier Baldan</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
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<tr>
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<th>Sign:</th>
<th>Date:</th>
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<tbody>
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<td></td>
<td></td>
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</tbody>
</table>

<table>
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<th>Sign:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2 Size, frequency and localization of leaks

**ASSUMPTIONS REGISTER**

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<th>Date:</th>
<th>2019-05-16</th>
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<tbody>
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<td>Size, frequency and localization of leaks</td>
<td>Revision:</td>
<td>1</td>
</tr>
<tr>
<td>Category:</td>
<td>Analytical assumption</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Specifications:**

The leak frequencies for the process equipment (except for the flexible hose used for loading and for the LNG tank) are assessed based on counting of equipment represented in the P&IDs (ref. /3/).

The leak frequency assessment is based on the following additional assumptions:

- The DNV GL software LEAK v3.3 is used;
- The process conditions applied are equivalent to the ones during normal operation (presented in 4.2);
- The leak frequencies are distributed by leak sizes as presented in Table 3-3;
- It is assumed that the process equipment is filled with LNG at all time up to the valves directly upstream the product vaporizers (PV1/PV2); and
- It is assumed that the sections downstream the product vaporizers (PV1/PV2) are filled with gas.

**Table 3-3 Leak size distribution according to hole size (mm)**

<table>
<thead>
<tr>
<th>Size</th>
<th>Lower limit (mm)</th>
<th>Upper limit (mm)</th>
<th>Representative size used in the model (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>1</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Medium</td>
<td>10</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>Large/Rupture</td>
<td>50</td>
<td>-</td>
<td>Varying, depending on the value obtained from LEAK. The maximum is set as fullbore rupture.</td>
</tr>
</tbody>
</table>

For the loading hose, two releases sizes are considered. Large releases consider the full-bore rupture of the hose (up to 50 mm), while small releases consider as representative size 10% of the hose diameter. The hole sizes and the failure frequency for the loading hose follow the Shell recommendations (ref. /14/).

The failure frequency for the loading hose is presented in Table 3-4. The frequency is distributed as 80% for small releases and 20% for full bore releases (in line with assumptions agreed with DSB for other studies). Note that in the Shell report is assumed to have a duration of 1 hour.

**Table 3-4 Leak frequencies applied for the LNG transfer hose (truck loading)**

<table>
<thead>
<tr>
<th></th>
<th>Frequency (/transfer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>2.32E-07</td>
</tr>
<tr>
<td>Large/Rupture</td>
<td>5.80E-08</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2.87E-07</strong></td>
</tr>
</tbody>
</table>
The evaluation of release frequencies from the LNG tank follows the OGP guidelines (ref. /10/). The adopted leak frequencies for the leak sizes distribution defined in Table 3-3 are presented in Table 3-5. The catastrophic rupture of the tank is not considered in the analysis as the scenario is assessed as not credible.

Table 3-5 Leak frequencies adopted for the LNG tank

<table>
<thead>
<tr>
<th>Leak size</th>
<th>Frequency (/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>3.50 x 10^{-5}</td>
</tr>
<tr>
<td>Medium</td>
<td>7.10 x 10^{-6}</td>
</tr>
<tr>
<td>Large</td>
<td>4.77 x 10^{-6}</td>
</tr>
</tbody>
</table>

The chosen leak locations for BNG Bodø are represented by the red dots in Figure 3-1. Leak location 1 refers to normal operation, while leak location 2 is used to account of the additional releases during loading of the LNG tank. The height of the leak point is assumed to be 0.5 meter above the ground level for both cases.

The majority of the equipment are located in the tank area where the tank, the vaporizers and equipment required for pressure control are located.

For simplification, the leak location of the LNG truck is assumed to be at the located in the tank area.

For the gas pipeline (underground and subsea), the leakage points are assumed throughout the length of the whole segment (and modelled as a leakage point every 50 m).
The release frequency for the pipeline is evaluated using the DNV GL Recommended Practice (Ref. /13/). The failure frequency is set as 1.70E-08 per km/year. This value is then modified using a score system in order to address that the pipeline is buried or subsea.

The final failure frequencies adopted in the study for the gas pipeline are summarized in Table 3-6.

Table 3-6 Failure frequencies adopted for the gas pipeline

<table>
<thead>
<tr>
<th>Segment</th>
<th>Frequency (/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas pipeline underground (before subsea)</td>
<td>1.51E-04</td>
</tr>
<tr>
<td>Gas pipeline subsea</td>
<td>1.50E-04</td>
</tr>
<tr>
<td>Gas pipeline underground (after subsea)</td>
<td>7.37E-05</td>
</tr>
</tbody>
</table>

Implication of assumption:
The location of the leak point and the estimated leak frequencies associated is an input used to calculate the risk levels during the different activities and the yearly risk for the local population.

References for this assumption:
/3/ Barents Naturgass Bodø LNG terminal, P&ID, Tegn. Nr. K3014871_R1, 23/11/05
/14/ Shell Global Solutions, LNG Hose Failure Probability, SR.14.11.417

Prepared by: Marta Bucelli  Sign: MARBUC  Date: 2019-05-16
Internal Verification: Olivier Baldan  Sign: OBAL  Date: 2019-05-16
Comment from BNG:

Approved by BNG:  Sign:  Date:
3.3 Leak durations and leak rates

ASSUMPTIONS REGISTER

<table>
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<tr>
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</thead>
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<tr>
<td>Subject</td>
<td>Leak durations and leak rates</td>
</tr>
<tr>
<td>Category</td>
<td>Analytical assumptions</td>
</tr>
</tbody>
</table>

Specifications:
The leak duration of each segment is estimated by the software SAFETI. The leak duration is linked to the inventory of the isolatable segment and the duration of the ESD procedure taking into consideration the time for detecting, initiating, and isolating the segments.

The estimation is based on the following inputs:

- Time for detection and initiation of the ESD system, see 3.10;
- LNG inventory considered in the segments, see 4.2;
- Adjacent inventory of isolatable segments when isolation fails, see 4.2; and
- Representative leak sizes, see 3.2.

This assessment considers both cases with successful and failure of the ESD system.

Note that SAFETI cannot compute a leak duration longer than 3600 seconds.

Implication of assumption:
The duration of a leak impacts directly its outcomes and consequences.

References for this assumption:

Prepared by: Marta Bucelli  Sign: MARBUC  Date: 2019-01-25
Internal Verification: Olivier Baldan  Sign: OBAL  Date: 2019-01-25

Comment from BNG:

Approved by BNG:  Sign:  Date:
### 3.4 Leak direction

<table>
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<tr>
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<td>0</td>
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<tr>
<td>Subject:</td>
<td>Leak direction</td>
</tr>
<tr>
<td>Category:</td>
<td>Analytical assumption</td>
</tr>
</tbody>
</table>

**Specifications:**

When a leak occurs, the leak can go in all directions. However, the horizontal leak direction is known to give the largest impacted zone.

In this assessment, it is assumed conservatively that all the leaks have horizontal direction.

The releases are modelled as *impinged* due to the presence of obstacles close to the tank.

**Implication of assumption:**

The leak direction impacts the calculation of dispersion and impact the outcomes of a leak.

**References for this assumption:**

- Prepared by: Marta Bucelli  
  Sign: MARBUC  
  Date: 2019-01-25

- Internal Verification: Olivier Baldan  
  Sign: OBAL  
  Date: 2019-01-25

**Comment from BNG:**

- Approved by BNG: 
  Sign:  
  Date:
3.5 Immediate and delayed ignition

ASSUMPTIONS REGISTER

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<th>Date:</th>
<th>2019-05-16</th>
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<tr>
<td>Revision:</td>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>Subject:</td>
<td>Immediate and delayed ignition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category:</td>
<td>Analytical assumption</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Specifications:

The ignition depends on type of ignition and ignition source and on the leak size.

Immediate ignition is here defined as ignition due to nearby sources that occurs before an appreciable vapour cloud is produced. Therefore, in case of immediate ignition, no explosion outcomes are considered.

The probability of immediate ignition shown in Table 3-7 is based on the JIP ignition model (ref. /4/), commonly used for oil and gas QRAs and it depends on the release rate (kg/s).

Table 3-7 Immediate ignition probability (ref. /4/)

<table>
<thead>
<tr>
<th>Leak Size</th>
<th>Leak rates</th>
<th>Immediate ignition probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>0.1-1 kg/s</td>
<td>1 E-04</td>
</tr>
<tr>
<td>Medium</td>
<td>1-10 kg/s</td>
<td>1 E-03</td>
</tr>
<tr>
<td>Large</td>
<td>&gt;10 kg/s</td>
<td>1 E-02</td>
</tr>
</tbody>
</table>

For delayed ignition, there is a lapse of time between the start of the leak and its ignition.

Two analyses are carried out. One considering the ignitions in the area (case A) and one with unitary delayed ignition (case B). The two cases differ for the set-up of the delayed ignition, as described in the following:

- **Case A (ignition sources modelled)**
  
  This case is useful from risk management perspective to assess which ignition source should be reduced and/or controlled.

  The ignitions in the area around the LNG tank are considered. For the BNG Bodø installation these are mainly due to individuals and traffic (see assumption 3.6 and 3.8 respectively of this report), electrical equipment and static electricity in the area (see below).

  The probability of delayed ignition is evaluated according to the following factors:

  - Leak location;
  - Exposure to the ignition source (duration);
  - Duration of operability of the ignition sources; and
  - Intensity of the ignition source.

  For buildings and houses, the intensity of ignition is based on ventilation. The probability of ignition is set as 1 when the building presents an open flame. Otherwise, the probability of ignition is set as 0.1 for an exposure of 600 seconds.
The ignition sources considered for Bodø are presented in Figure 3-2 and in Table 3-11. Every ignition source is presented with its operability in function of time and its intensity of ignition.

The equipment within the BNG unit are modelled as EX compliant.

All the sources that are not linked to the LNG terminal are considered non EX-compliant.

- **Case B (unitary delayed ignition)**

  This case complies with the requirement set in DSB guidelines. (Ref. /1/).

  The delayed ignition for every release scenario is set equal to 1. This means that every release, if not immediate ignited, will ignite when its dispersion is at its maximum with a probability of ignition of 100%. This case is required by DSB regulations [Ref. /1/].

**Implication of assumption:**

The results of the assessment are dependent of the ignition probabilities assumed. If the assumptions change, the results will be impaired. The change of ignition frequencies impact directly the fire probabilities and can lead to alter the type of mitigation measures required.

The immediate ignition probability has a direct influence on the risks associated with jet and pool-fire risks to personnel and assets. The immediate ignition probability is based on the JIP study (Ref. /4/).

Delayed ignition probabilities have a key influence in determining the likelihood of flash fire and explosion hazards and the extent of them. This has been estimated according to input from BNG ans it is believed to be robust.

**References for this assumption:**


**Prepared by:** Marta Bucelli  
Sign: MARBUC  
Date: 2019-05-16

**Internal Verification:** Olivier Baldan  
Sign: OBAL  
Date: 2019-05-16

**Comment from BNG:**

**Approved by BNG:**

**Additional information to assumption 3.5**

The ignitions probabilities (see Table 3-8 and Table 3-9) are based on the JIP (ref. /4/). The data found in this report are used as basis for defining the frequencies in this assessment. Adjusting factors (see
Table 3-10) are applied for taking in consideration the following factors:
- Age of installation;
- Maintenance program, assuming a normal level of maintenance; and
- Technology factor, assuming that the latest technology is applied.

### Table 3-8 Ignition probability for discrete ignition sources

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Basis for Ignition probability per second of exposition</th>
<th>Adjusting factor</th>
<th>Applied Ignition probability per second of exposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical equipment</td>
<td>2.7E-08 /m²</td>
<td>0.54</td>
<td>1.46E-08 /m²</td>
</tr>
<tr>
<td>Other equipment</td>
<td>2.1E-09 /m²</td>
<td>0.54</td>
<td>9.18E-09 /m²</td>
</tr>
<tr>
<td>Others</td>
<td>1.7E-08 /m²</td>
<td>1</td>
<td>1.70E-08 /m²</td>
</tr>
</tbody>
</table>

### Table 3-9 Ignition probability for continuous ignition sources

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Basis for Ignition probability per second of exposition</th>
<th>Adjusting factor</th>
<th>Applied Ignition probability per second of exposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical equipment</td>
<td>2.6E-06/m²</td>
<td>0.54</td>
<td>1.4E-06/m²</td>
</tr>
<tr>
<td>Other equipment</td>
<td>2.6E-06/m²</td>
<td>0.54</td>
<td>1.4E-06/m2</td>
</tr>
</tbody>
</table>

### Table 3-10 Adjusting Factors

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Age factor</th>
<th>Maintenance factor</th>
<th>Technology factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical equipment</td>
<td>0.9</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Other equipment</td>
<td>0.9</td>
<td>1</td>
<td>0.6</td>
</tr>
<tr>
<td>Others</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 3-11 Ignition Sources

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Ignition intensity</th>
<th>Operation factor</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Commercial building (in construction)</td>
<td>0.1 per 600 s exposure</td>
<td>8 h per day (33%)</td>
<td>It takes into account electrical equipment of buildings (compressors, lightings, heating systems). Note that the ignition intensity assumes that the LNG must enter the housing for being exposed to ignitions sources.</td>
</tr>
<tr>
<td>2</td>
<td>Commercial building</td>
<td>0.1 per 600 s exposure</td>
<td>8 h per day</td>
<td>It takes into account electrical equipment of buildings (compressors, lightings, heating systems). Note that the ignition intensity assumes that the LNG must enter the housing</td>
</tr>
<tr>
<td></td>
<td>Location</td>
<td>Ignition Intensity</td>
<td>Exposure Time</td>
<td>Description</td>
</tr>
<tr>
<td>---</td>
<td>-------------------------</td>
<td>--------------------</td>
<td>---------------</td>
<td>----------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>3</td>
<td>Local control room</td>
<td>0.1 per 600 s exposure</td>
<td>12 h per day</td>
<td>It takes into account electrical equipment in control room (switchboards, lighting, heating). Note that the ignition intensity assume that the LNG must enter the housing for being exposed to ignitions sources, and that equipment is automatically deactivated if a leak is detected.</td>
</tr>
<tr>
<td>4</td>
<td>Workshop/Warehouse</td>
<td>0.1 per 600 s exposure</td>
<td>8 h per day</td>
<td>It takes into account electrical equipment of houses (lightings, heating systems). Note that the ignition intensity assume that the LNG must enter the housing for being exposed to ignitions sources.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Point Sources</strong></td>
</tr>
<tr>
<td>5</td>
<td>Cold storage</td>
<td>0.1 per 600 s exposure</td>
<td>8 h per day (33%)</td>
<td>It takes into account electrical equipment of buildings (compressors, lightings, heating systems). Note that the ignition intensity assumes that the LNG must enter the housing for being exposed to ignitions sources.</td>
</tr>
<tr>
<td>6</td>
<td>Ship</td>
<td>0.5 per 60 s exposure</td>
<td>4 h per day 15%</td>
<td>The parking is mostly used by workers in the area. As it is difficult to know when the engines can be on, then it is conservatively assumed that the engine is always on.</td>
</tr>
<tr>
<td>7</td>
<td>Parking</td>
<td>0.4 per 60 s exposure</td>
<td>8 h per day (33%)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>LNG truck</td>
<td>0.4 per 60 s exposure</td>
<td>7% (according to loading frequency)</td>
<td>It considers the ignition sources of the truck itself (engine, electrical equipment). The truck is there only during filling operation.</td>
</tr>
<tr>
<td>9</td>
<td>Trucks/excavators</td>
<td>0.4 per 60 s exposure</td>
<td>8 h per day</td>
<td>It considers the ignition sources of the truck itself (engine, electrical equipment).</td>
</tr>
</tbody>
</table>
3.6 Ignition sources of individuals

ASSUMPTIONS REGISTER

<table>
<thead>
<tr>
<th>Assumption No.</th>
<th>3.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>Ignition sources of individuals</td>
</tr>
<tr>
<td>Category</td>
<td>Analytical assumption</td>
</tr>
</tbody>
</table>

Specifications:
The individuals included in this assessment are considered as ignition source. The ignition probability of each individual is assumed to be 1.68E-04 per second of exposition to flammable material. This value takes into account the normal behavior of an individual in residential/city areas. It should be noted that individuals in the loading area are normally trained and experienced individual, and it could be argued that the ignition probability should be lower. Nevertheless, the ignition probability is conservatively kept as 1.68E-04 per individual per second of exposition.

The distribution of individual is presented in assumption 4.2.

Implication of assumption:
Impact on fire frequencies and explosion if these populations are exposed to any gas releases.

References for this assumption:

Prepared by: Marta Bucelli
Sign: MARBUC
Date: 2019-01-25

Internal Verification: Olivier Baldan
Sign: OBAL
Date: 2019-01-25

Comment from BNG:

Approved by BNG:
Sign: 
Date:
3.7 Obstructed areas

ASSUMPTIONS REGISTER

<table>
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<th>Assumption No.</th>
<th>Date: 2019-01-25</th>
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<td>Subject:</td>
<td>Obstructed areas</td>
</tr>
<tr>
<td>Category:</td>
<td>Analytical assumption</td>
</tr>
</tbody>
</table>

Specifications:

Different obstructed areas are defined for the plant. They are listed in Table 3-12. The Multi Energy model from TNO has been adopted. The parameter (curve number and blockage ratio) used to describe the different obstructions are presented in Table 3-12. The Multi-Energy curve number describes the explosion strength and it may vary from 1 (lower strength) to 10 (maximum strength). The blockage ration describes the volume of the obstruction and it varies from 0 to 1.

Note that obstruction related to the LNG truck listed in to Table 3-12 is included in the study only during the loading of the LNG tank.

Figure 3-3 shows the different obstructions at the BNG plant in Bodø.

Table 3-12 Obstructed areas considered in the study for the plant

<table>
<thead>
<tr>
<th>ID</th>
<th>Obstruction region</th>
<th>Multi-Energy curve</th>
<th>Blockage ratio</th>
</tr>
</thead>
</table>
Figure 3-3 Obstruction areas considered in the analysis.

Implication of assumption:
The definition of obstructed areas and the multi energy curves will influence the explosion risk with effects on both the personnel risk and escalation risk.

The definition of obstructed areas and the multi energy is based on engineering judgement and best practice. The ME curve is mostly correct near the explosion area.

References for this assumption:

<table>
<thead>
<tr>
<th>Prepared by:</th>
<th>Sign:</th>
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<tbody>
<tr>
<td>Marta Bucelli</td>
<td>MARBUC</td>
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<tr>
<td>Olivier Baldan</td>
<td>OBAL</td>
<td>2019-01-25</td>
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<thead>
<tr>
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<th>Sign:</th>
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### 3.8 Traffic

**ASSUMPTIONS REGISTER**

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</tr>
<tr>
<td>Category:</td>
<td>Analytical assumption</td>
<td></td>
</tr>
</tbody>
</table>

**Specifications:**

Roads and parking areas considered in the study are presented in Figure 3-4. The details are provided in Table 3-13.

In Bodø, road Bursøyveien (identified as 1 in Figure 3-4) is considered to be a dead-end road. It gives access to several industrial activities, offices and to a memorial site.

There are no specific rules applied to the traffic assumed for this assessment.

The average traffic speed and the ignition parameters for each road considered in this study are listed in Table 3-14.

**Implication of assumption:**

The traffic impacts the fire and explosion frequencies if these sources are reached by flammable materials.

The ignition intensity (0.1 for 10 s exposure time) is an uncertain parameter and it is based on DNV GL expert judgment.

**References for this assumption:**


**Prepared by:** Marta Bucelli  
**Sign:** MARBUC  
**Date:** 2019-01-25

**Internal Verification:** Olivier Baldan  
**Sign:** OBAL  
**Date:** 2019-01-25

**Comment from BNG:**

**Approved by BNG:**

**Sign:**  
**Date:**
Figure 3-4 Roads and parking areas considered in the study

Table 3-13 Road traffic considered in the study

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Type</th>
<th>Number of vehicles per year</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Burøyveien</td>
<td>Secondary Road</td>
<td>2500 vehicles</td>
<td>Road to access the industrial activities and memorial site.</td>
</tr>
<tr>
<td>2</td>
<td>Road to the quay</td>
<td>Secondary Road</td>
<td>1500 vehicles</td>
<td>Road to access the quay and industrial activities</td>
</tr>
<tr>
<td>3</td>
<td>Parking</td>
<td>Parking area</td>
<td>300 vehicles</td>
<td>Parking for personnel</td>
</tr>
<tr>
<td>4</td>
<td>Road to industrial activities</td>
<td>Private road</td>
<td>120 vehicles</td>
<td>Road to access the industrial activities</td>
</tr>
</tbody>
</table>

Table 3-14 Average speed and ignition parameters considered for each road

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Average speed (km/h)</th>
<th>Ignition Probability (fraction)</th>
<th>Time period (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Burøyveien</td>
<td>50</td>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>Road to the quay</td>
<td>50</td>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Parking</td>
<td>20</td>
<td>0.1</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Road to industrial activities</td>
<td>50</td>
<td>0.1</td>
<td>10</td>
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### 3.9 ESD philosophy

**ASSUMPTIONS REGISTER**

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<th>3.9</th>
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<tr>
<td>Subject:</td>
<td>ESD Philosophy</td>
</tr>
<tr>
<td>Category:</td>
<td>Analytical assumption</td>
</tr>
</tbody>
</table>

**Specifications:**

**ESD system – Leak & Fire detection**

The ESD system can be triggered at different locations of the LNG terminal inside the tank area and in the local control room. There are two gas detectors at the tank area and one in the local control room. All the gas detectors are located 2 m above the ground. There is one flame detector located in the tank area, and one temperature sensor detecting liquid leaks. There are three push-buttons, located by the filling point in the tank area, outside the local control room and inside the local control room.

Any triggering of the ESD system will immediately cause the closure of all automated valves on the installation.

The same ESD duration is assumed during filling of the reservoir by the LNG truck.

**Implication of assumption:**

Time of detection and isolation impact the leak duration and consequently it impacts the consequences of a release and the risk level related to it.

**References for this assumption:**

<table>
<thead>
<tr>
<th>Prepared by:</th>
<th>Marta Bucelli</th>
<th>Sign: MARBUC</th>
<th>Date: 2019-01-25</th>
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<td>Date: 2019-01-25</td>
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<tr>
<td>Approved by BNG:</td>
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### 3.10 ESD time

<table>
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<td>Subject:</td>
<td>ESD time</td>
</tr>
<tr>
<td>Category:</td>
<td>Analytical assumption</td>
</tr>
</tbody>
</table>

**Specifications:**

**ESD time including detection, initiation and completion**

A total duration of 90 seconds for initiation and completion of the ESD process is considered in the study.

Given that a leak starts at time $t=0$ seconds. Detection time is the time needed between the beginning of the leak and its detection. Isolation time is the duration required between detection time and complete closure of the safety valves. This time takes into account as well the time needed by an operator to push a push-button.

This duration is based on the following assumptions:

- During the totality of the loading operation, the operator in charge of the operation have a good overview and control of the equipment containing the LNG;
- The operators are familiar with the equipment and the operation and known all the procedures to apply in case of detection of a leakage;
- The emergency push-button are present in a sufficient manner and located in a reachable distance for all leakage direction.

**Implication of assumption:**

The ESD time impacts the duration of any release and consequently the volume released.

**References for this assumption:**

Prepared by: Marta Bucelli  
Sign: MARBUC  
Date: 2019-01-25

Internal Verification: Olivier Baldan  
Sign: OBAL  
Date: 2019-01-25

Comment from BNG:

Approved by BNG:  
Sign:  
Date:
### 3.11 Probability of failure of the ESD system

<table>
<thead>
<tr>
<th>ASSUMPTIONS REGISTER</th>
<th>Date: 2019-05-16</th>
</tr>
</thead>
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<td>Assumption No.: 3.11</td>
<td>Revision: 1</td>
</tr>
<tr>
<td>Subject: ESD failure probability</td>
<td></td>
</tr>
<tr>
<td>Category: Analytical assumption</td>
<td></td>
</tr>
</tbody>
</table>

**Specifications:**

The isolation and shutdown of the process can be triggered automatically or manually, given operators are present during the loading operation.

It is assumed that the Probability of Failure on Demand (PFD) of each ESD system is 10% per demand.

During the filling of the tank, it is assumed that the truck has its own ESD system and the driver or an operator can manually trigger it. The LNG truck has its own isolation valve.

Note that the ESD system on the LNG truck is assumed to have a failure rate of 10%.

The same failure probability of 10% has been applied for the subsea/buried pipeline.

The detection time has been set conservatively as 3600 s for small releases (i.e. the ESD system does not detect the release) and as 30 s for medium, large and rupture.

**Implication of assumption:**
Failure on demand of isolation will lead to longer leak/fire durations.

**References for this assumption:**
DNV GL expert judgement

<table>
<thead>
<tr>
<th>Prepared by: Marta Bucelli</th>
<th>Sign: MARBUC</th>
<th>Date: 2019-01-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Verification: Olivier Baldan</td>
<td>Sign: OBAL</td>
<td>Date: 2019-01-25</td>
</tr>
</tbody>
</table>

**Comment from BNG:**
3.12 Meteorological data and Windrose

ASSUMPTIONS REGISTER

<table>
<thead>
<tr>
<th>Assumption No.</th>
<th>Revision</th>
<th>Date: 2019-01-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject: Meteorological data and windrose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category: Analytical assumption</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Specifications:
The meteorological data for Bodø are based on the closest meteorological stations available on [www.eklima.no](http://www.eklima.no) (Bodø VI). The data are gathered over the last 10 years and considered representative for the study.

The meteorological parameters applied in the assessment are as listed in Table 3-15. The windrose and wind distribution are presented in Figure 3-5.

Table 3-15 Meteorological parameters considered for Bodø in the study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Notes and references</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric temperature</td>
<td>1.7°C</td>
<td>Mean value based on weather station data.</td>
</tr>
<tr>
<td>Atmospheric pressure</td>
<td>101400 N/m²</td>
<td>Representative atmospheric pressure over sea surface.</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>70%</td>
<td>Default representative value.</td>
</tr>
<tr>
<td>Ground temperature</td>
<td>1.7°C</td>
<td>Temperature equals to atmospheric temperature.</td>
</tr>
<tr>
<td>Surface roughness length</td>
<td>1 m</td>
<td>Regular large obstacles.</td>
</tr>
<tr>
<td>Solar Flux</td>
<td>500 W/m²</td>
<td>Default representative value</td>
</tr>
<tr>
<td>Height of applied wind speed</td>
<td>10 m</td>
<td>Standard height for meteorological data measurements.</td>
</tr>
</tbody>
</table>

Implication of assumption:
The dispersion and consequences assessment are sensible to the meteorological data and the wind distribution. Any changes in these assumptions will impact the risk results.

References for this assumption:

Prepared by: Marta Bucelli
Sign: MARBUC
Date: 2019-01-25

Internal Verification: Olivier Baldan
Sign: OBAL
Date: 2019-01-25

Comment from BNG:

Approved by BNG:
Sign:
Date:
Figure 3-5 Wind rose for Bodø (www.eklima.no)
## 4 TECHNICAL ASSUMPTIONS

### 4.1 Impounding areas

<table>
<thead>
<tr>
<th>ASSUMPTIONS REGISTER</th>
<th>Date: 2019-01-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumption No.:</td>
<td>4.1</td>
</tr>
<tr>
<td>Revision:</td>
<td>0</td>
</tr>
<tr>
<td>Subject:</td>
<td>Impounding areas</td>
</tr>
<tr>
<td>Category:</td>
<td>Technical assumption</td>
</tr>
</tbody>
</table>

**Specifications:**

It is assumed that BNG installation at Bodø has an impounding basin made of concrete. The concrete area is delimited with a concrete wall of 30 cm. The area of the concrete area is assessed to be approximately 220 m².

The area is built in the manner that any leakage will be directed towards the drain with a water lock to prevent any LNG from escaping.

It is assumed that the LNG truck is parking on an area where there is no impounding basin that can collect leakages from the truck.

**Implication of assumption:**

The assumption has a key influence on the consequence modelling.

**References for this assumption:**

Input from BNG.

**Prepared by:** Marta Bucelli  
Sign: MARBUC  
Date: 2019-01-25

**Internal Verification:** Olivier Baldan  
Sign: OBAL  
Date: 2019-01-25

**Comment from BNG:**

Approved by BNG  
Sign:  
Date:
4.2 Segmentation of LNG system

ASSUMPTIONS REGISTER

<table>
<thead>
<tr>
<th>Assumption No.</th>
<th>4.2</th>
<th>Date: 2019-05-16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>Segmentation of LNG system</td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Technical assumption</td>
<td></td>
</tr>
</tbody>
</table>

Implication of assumption:
A segment is defined as a section that can be isolated when the ESD system is triggered. This assessment considers only a system that includes the LNG truck, the storage tank and the equipment down to the gas grid.

The ESD valves are used to segment the system (see also 3.9). The segmentation is defined as follows in Table 4-1. It is assumed that all the segments contain natural gas at liquid/gas state.

Table 4-1 Segmentation adopted in the study

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Segments</th>
<th>Volume (m³)</th>
<th>Pressure (barg)</th>
<th>Temperature (°C)</th>
<th>Flow rate (m³/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG Truck</td>
<td>LNG truck tank</td>
<td>60</td>
<td>3</td>
<td>-153</td>
<td>NA</td>
</tr>
<tr>
<td>Inlet (Hose)</td>
<td>From ESD valve on LNG truck to BV1A and BV3A</td>
<td>0.04</td>
<td>6</td>
<td>-142</td>
<td>40</td>
</tr>
<tr>
<td>LNG tank</td>
<td>LNG storage tank</td>
<td>127</td>
<td>6</td>
<td>-142</td>
<td>NA</td>
</tr>
<tr>
<td>LNG tank piping</td>
<td>LNG storage tank piping</td>
<td>0.06</td>
<td>6</td>
<td>-142</td>
<td>40</td>
</tr>
<tr>
<td>Piping to evaporators</td>
<td>From BV2A to product vaporizers PV1/PV2</td>
<td>0.38</td>
<td>6</td>
<td>-142</td>
<td>4</td>
</tr>
<tr>
<td>Evaporators</td>
<td>From PV1/PV2 to pressure regulators R1/R2</td>
<td>0.09</td>
<td>6</td>
<td>+5</td>
<td>2500 Nm3/h</td>
</tr>
<tr>
<td>Piping to NG pipeline</td>
<td>From R1/R2 to A18</td>
<td>1.84</td>
<td>4</td>
<td>+10</td>
<td>2500 Nm3/h</td>
</tr>
<tr>
<td>New evaporators</td>
<td>Not yet defined</td>
<td>0.09</td>
<td>6</td>
<td>+5</td>
<td>2500 Nm3/h</td>
</tr>
<tr>
<td>Pressure building unit at the LNG tank</td>
<td>From BV1A to E02A/B</td>
<td>0.38</td>
<td>6</td>
<td>-142</td>
<td>NA</td>
</tr>
<tr>
<td>Pipeline</td>
<td>From A18 to Battery Limits (as in drawings, Ref. /13/)</td>
<td>19</td>
<td>4</td>
<td>+5</td>
<td>2500 – 400Nm3/h</td>
</tr>
</tbody>
</table>

Implication of assumption:
The segmentation impacts directly the duration of leak and the consequences of corresponding events.

References for this assumption:

Prepared by: Marta Bucelli  
Sign: MARBUC  
Date: 2019-05-16
5 OPERATIONAL ASSUMPTIONS

5.1 Operation phases

ASSUMPTIONS REGISTER

<table>
<thead>
<tr>
<th>Assumption No.</th>
<th>Subject</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Operational phases</td>
<td>Operational assumptions</td>
</tr>
</tbody>
</table>

Specifications:

Two periods are considered for the industrial site:

- High season, assumed to be from October to April (7 months); and
- Low season, assumed to be from May to September (5 months).

The LNG tank is filled with LNG at all time. The assessment covers the standby/vaporizing and filling of main tank. No other activities are considered in this assessment.

The yearly average loading frequency has been considered in the study.

The number of operations described in Table 5-1 is assumed.

The study assumes the vaporization as continuous.

Table 5-1   Number of operations

<table>
<thead>
<tr>
<th>Type of activity</th>
<th>High Season</th>
<th>Low Season</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filling of LNG tank per week</td>
<td>7</td>
<td>1</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>Vaporizing to grid (MW)</td>
<td>25</td>
<td>4</td>
<td>Continuously</td>
</tr>
</tbody>
</table>

Implication of assumption:

The duration and the number of operations impact the leak frequencies and the contribution of the different events assumed during the assessment.

References for this assumption:

Prepared by: Marta Bucelli  
Sign: MARBUC  
Date: 2019-01-25

Internal Verification: Olivier Baldan  
Sign: OBAL  
Date: 2019-01-25

Comment from BNG:
5.2 Manning level and distribution

ASSUMPTIONS REGISTER

<table>
<thead>
<tr>
<th>Assumption No.:</th>
<th>5.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revision:</td>
<td>0</td>
</tr>
<tr>
<td>Subject:</td>
<td>Population distribution</td>
</tr>
<tr>
<td>Category:</td>
<td>Operational assumption</td>
</tr>
</tbody>
</table>

Specifications:
The population used it the yearly average.
The assessment is based on the following population groups:

- 1st party: BNG personnel or operators dedicated to the filling operations;
- 2nd party: Individuals related to the commercial activity of the building and quay; and
- 3rd party: Individuals working in the proximity of the area and bypassers on Burøyveien.

More details about the groups are presented in the below in Table 5-2. The inside/outside fraction in the table represents the time the personnel spends inside or outside the buildings.

Implication of assumption:
The assumption impacts the exposure of the population to specific outcomes.

Personnel risk is directly influenced by the numbers of personnel exposed to hazardous events and hence the PLL results are sensitive to the manning assumptions. FAR is an average measure of risk, either for all personnel at a facility or for defined groups; it is also dependent on the manning assumptions.

References for this assumption:

Prepared by: Marta Bucelli Sign: MARBUC Date: 2019-01-25
Internal Verification: Olivier Baldan Sign: OBAL Date: 2019-01-25
Comment from BNG:

Approved by BNG: Sign: Date:
Table 5-2 Population considered for Bodø LNG

<table>
<thead>
<tr>
<th>No</th>
<th>Group</th>
<th>Population present during operation</th>
<th>Presence factor (h/day)</th>
<th>Inside fraction</th>
<th>Outside fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1st party</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>LNG tank and control room</td>
<td>1</td>
<td>2 (only during loading of the tank)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2nd party</td>
<td>10</td>
<td>8</td>
<td>0.9</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>3rd party</td>
<td>80</td>
<td>8</td>
<td>0.75</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Figure 5-1 Population areas considered in the study.
6 REFERENCES


/2/ Retningslinjer for kvantitative risikovurderinger for anlegg som håndterer farlig stoff, Rapportnr: 106535/R1, Rev: Sluttrapport A, 18 oktober 2017, DSB.

/3/ Barents Naturgass Boda LNG terminal, P&ID, Tegn. Nr. K3014871_R1, 23/11/05


/6/ UK HSE, Offshore Hydrocarbon Release Statistics, Offshore Technology, 2010


/12/ Barents Naturgass – Gassledning Burøya (26.03.2019). Received by email from Thomas Øien on 30-04-2019.


/14/ Shell Global Solutions, LNG Hose Failure Probability, SR.14.11.417
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