Risk assessment Study

Supplying Flemish ports with LNG as a marine fuel

Analysis of the external human risks

Executive Summary

September 2012

3500 Hasselt Maastrichtersteenweg 210 T. 011/22 32 40 F. 011/23 46 70
9032 Gent Industrieweg 118/4 T. 09/216 80 00 F. 09/375 36 17
1000 Brussel Clovislaan 82 T. 02/734 02 65 F. 02/734 61 80
5004 Bouge Route de Hannut 55 T. 081/22 60 82 F. 081/22 99 22

1. Introduction

Liquefied natural gas (LNG) presents itself as an environmentally benign alternative to the heavy fuel oils presently used for ship propulsion. The restrictions on the use of such oils to become effective in the near future has already resulted in a number of applications. It is expected that this trend will continue and that the use of LNG as engine fuel will rapidly increase.

As a consequence, ports will have to provide LNG bunkering facilities in addition to the traditional bunkering services. Bunkering requires transport, storage and transfer operations. Since LNG is a flammable cryogenic fluid, a number of safety risks are associated with the use of LNG. The scale of the operations and the quantities of LNG involved justify the need for a thorough analysis of these risks.

In the present study, the safety risks of LNG bunkering in the Flemish ports are analysed. The specific activities analysed are: the local storage, handling and transport of LNG, as well as the actual bunkering activities in the ports. In the first part of the study, the potential supply routes for LNG as a marine fuel in the Flemish ports are analysed. In the second part, the external human risks posed by the individual components in the supply chain are calculated in a generic way.

2. Analysis of the LNG supply chain for Flemish ports

2.1 Potential supply routes for LNG as a marine fuel

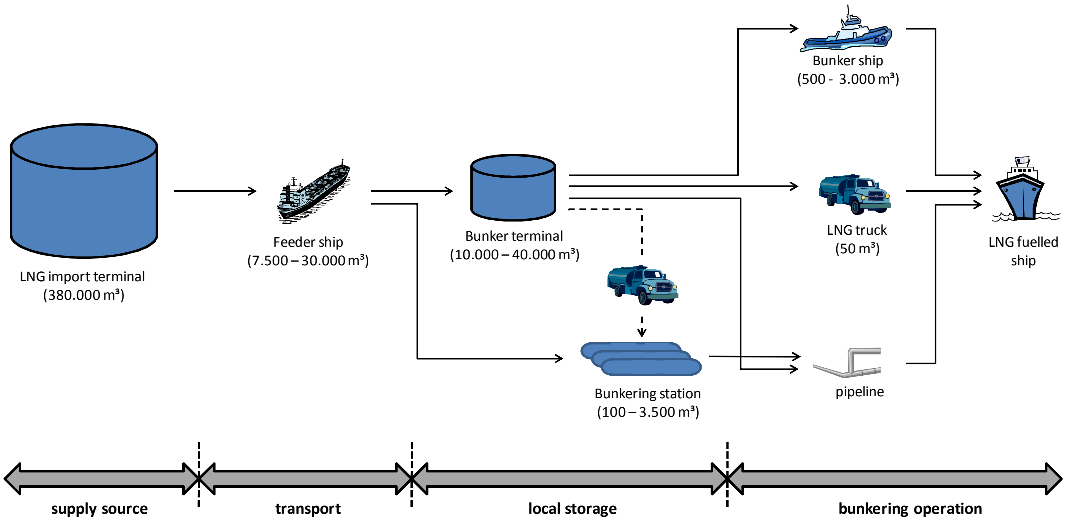
MAIN ROUTES – Considering the very close proximity to the LNG import terminal in the port of Zeebrugge and the export facilities offered at this terminal (e.g. loading of small LNG ships and LNG trucks), this terminal acts as an important potential source for the supply of LNG as a marine fuel in the Flemish ports.

As the demand for LNG as a marine fuel will increase and ships of different sizes will have to be bunkered at high frequencies, the need for local storage facilities in the ports will grow. The local storage can be realized by the construction of a medium-sized bunker terminal with a storage capacity of 10,000 to 40,000 m^3, but can also be achieved through the construction of small bunkering stations with storage capacities of 100 to 3,500 m^3.

Three types of bunkering solutions are considered feasible in the Flemish ports, namely ship to ship bunkering, truck to ship bunkering and tank to ship bunkering via pipeline.

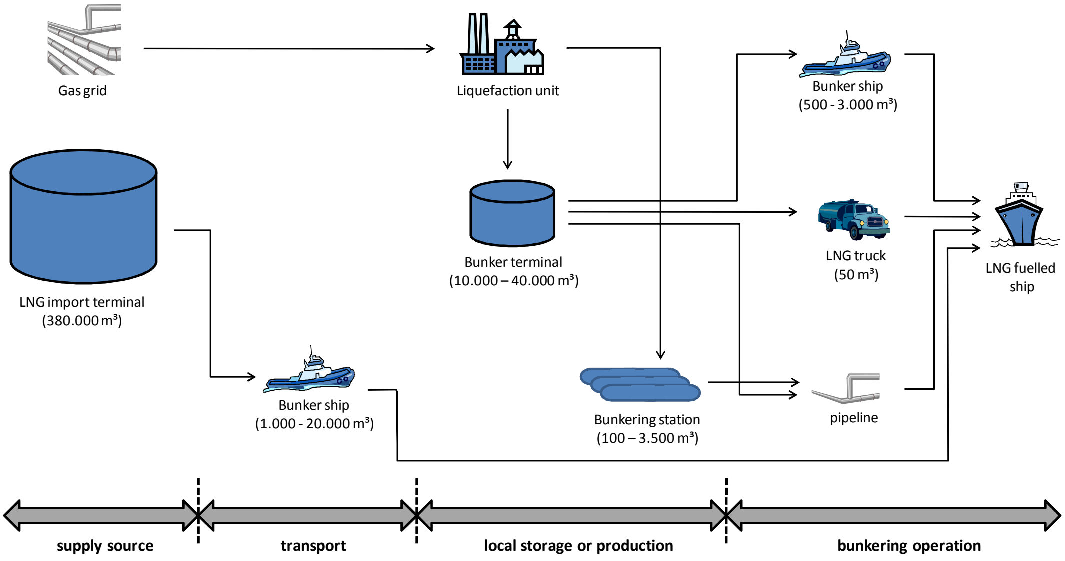
An overview of the main supply routes for the Flemish ports is given in Figure 2.1.1.

Figuur 2.1.1: Main supply routes for LNG as a marine fuel in the Flemish ports (excl. Zeebrugge)



ALTERNATIVE ROUTES – Potential alternative supply routes of LNG as a marine fuel in the ports of Antwerp and Ghent are shown in the figure below.

Figuur 2.1.2: Alternative supply routes for LNG as a marine fuel in the Flemish ports (excl. Zeebrugge)



LNG-fuelled ships in the ports of Antwerp and Ghent can be directly supplied with LNG via bunker ships which are loaded at the LNG import terminal. Such a supply route can be applied to ships with high fuel consumption (fuel tank ≥ 500 m³) during the initial development of LNG bunkering facilities in the ports.

Alternatively, LNG bunker terminals and bunkering stations can be provided with LNG through small- to medium-scale liquefaction units, which extract natural gas from the existing gas grid.

2.2 Separate components in the LNG supply chain

In the main report, the separate components in het LNG supply chain are described extensively with special attention to the characteristic dimensions of the installations and their technical specifications. Below, a brief overview will be given.

SHIPS – The LNG vessels (feeder ships and bunker ships) have a storage capacity of 500 to 30,000 m³. They are equipped with one to five cargo tanks of IMO tank type C. They are loaded and unloaded by means of flexible hoses or fixed arms at a flow rate of 200 to 6,000 m³ per hour.

TRUCKS – The LNG trucks have a maximum storage capacity of 23 metric tonne of LNG. With respect to the design of the cargo tank, a distinction is made between double-walled vacuum-insulated trucks and single-walled trucks insulated with polyurethane foam. The trucks are loaded by means of a flexible hose or a fixed arm at a flow rate of 50 to 100 m³ per hour and unloaded by means of a flexible hose at a typical flow rate of 50 m³ per hour.

BUNKER TERMINALS – Bunker terminals have a storage capacity of 10,000 to 40,000 m³. The LNG is stored in atmospheric single-walled, double-walled or full-containment tanks. These tanks have a volume of 10,000 to 40,000 m³. Therefore, a bunker terminal with a storage capacity of 40,000 m³ has, for example, two storage tanks of 20,000 m³ or one tank of 40,000 m³.

BUNKERING STATIONS – Bunkering stations have a storage capacity of 100 to 3,500 m³. The LNG is stored in double-walled vacuum-insulated pressure tanks with a volume of 100 to 700 m³.

LIQUEFACTION UNITS – Bunker terminals can be supplied by local liquefaction units. These units have a production capacity of 40,000 to 300,000 metric tonne per year. These medium-scale units are most commonly based on closed single or double refrigeration cycles with mixed components refrigerants.

A small bunkering station can be supplied by a liquefaction unit with a production capacity of 5,000 to 20,000 metric tonne per year. These small-scale units are predominantly based on a closed single refrigeration cycle with nitrogen as refrigerant.

BUNKERING OPERATION – Table 2.2.1 gives an overview of typical bunker volumes together with the applied flow rates for different types of LNG-fuelled ships.

Table 2.2.1: Typical bunker volumes en commonly applied bunker rates

Ship type	Bunker volume	Flow rate	Duration	Hose or arm diameter(s)
Service vessels, tug boats, Patrol boats and fishing boats	50 m³	60 m³/h	45 min	2x2" of 1x3"
Small RoRo and RoPax vessels	400 m³	400 m³/h	1 h	2x4" of 1x6"
Large RoRo and RoPax vessels	800 m³	400 m³/h	2 h	2x4" of 1x6"
Cargo vessels and small container ships	2.000 – 4.000 m³	1.000 m³/h	2 – 4 h	2x8" of 1x12"
Large tankers and container ships	10.000 m³	2.500 m³/h	4 h	2x10"
Very large oil tankers and container ships	20.000 m³	3.000 m³/h	7 h	2x12"

The bunkering of small volumes of LNG fuel is ideally done with pipelines (if the bunkering frequency is high) or with trucks (if the bunkering frequency is low), while the bunkering of large volumes is done with bunker ships or pipelines. The disadvantage of bunkering via pipeline is however that LNG-fuelled vessels have to come to a fixed location within the port.

3. Calculation of risk distances for the separate components

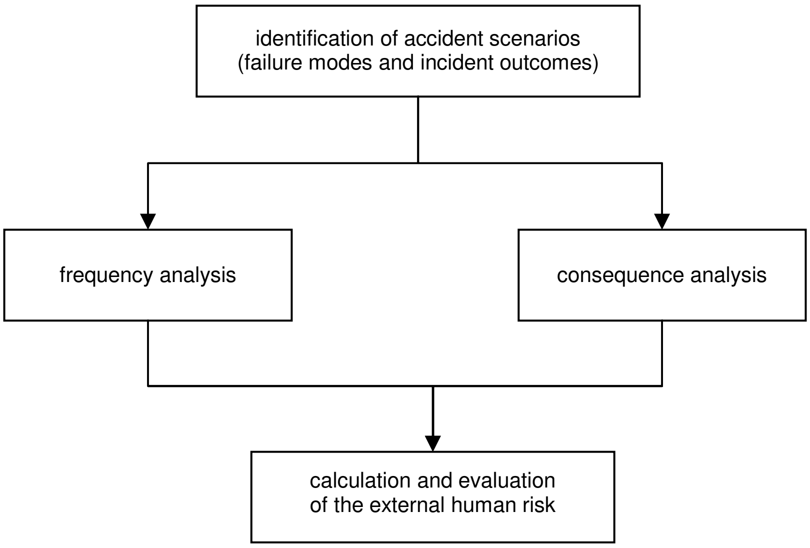
3.1 Applied methodology

RISK ANALYSIS METHODOLOGY – The external human risk that originates from the separate components in the LNG supply chain is determined by means of a quantitative risk analysis (QRA). It is presented in two different ways, namely as an individual human risk and as a societal risk(1).

The individual human risk is the probability for a single unprotected person to be killed by accidents related to the component considered and this over a period of 1 year. In the calculation it is assumed that the person is permanently present at the location. The individual risk depends upon the location (distance) of the person with respect to the location of the accident.

The societal risk expresses the probability that groups of people will die due to separate accidents related to the component and this over a period of one year. The societal risk depends upon the population density around the location of the accident and the size of the group considered. It is normally presented on an F-N-curve with the number of fatalities N in abscissa and the frequency per year F in ordinate.

Figure 3.1.1: Different steps in a quantitative risk analysis (QRA)



The risk analysis and evaluation are done in accordance with the existing technical guidelines from the competent Flemish authorities. The criteria for the evaluation of the individual risk that are used in Flanders are summarised in table 3.1.1.

---

(1) Because of the generic character of the risk analysis no specific population data are available. Therefore, the societal risk can only be evaluated qualitatively.

Table 3.1.1: Risk criteria imposed by the Flemish authorities

Location	Maximum allowable individual risk
Border of the establishment	10^{-5}/y
Residential areas	10^{-6}/y
Vulnerable locations (e.g. school grounds)	10^{-7}/y

SEPARATE COMPONENTS – The installations and activities that are studied in the QRA are atmospheric tanks (with a capacity up to 40,000 m³), vacuum-insulated pressure tanks (with a capacity up to 700 m³), loading and unloading of ships (with a flow rate up to 6,000 m³/h), loading and unloading of trucks (with a flow rate up to 100 m³/h), loading of LNG-fuelled ships (with a flow rate up to 3,000 m³/h) and small-scale liquefaction units (with a capacity up to 20,000 tonne per year).

In addition, the transport of LNG by road is studied for trucks with a capacity of 23 metric tonne and that by water is studied for (feeder and bunker) ships with capacities up to 30,000 m³.

RESULTS – The results of the QRA are normally given as risk contours connecting locations with the same individual risk. As it is assumed that these risk contours are more or less circular, the results of the QRA are given as risk distances, i.e. the distances at which the individual risk equals respectively 10^{-5}/y, 10^{-6}/y and 10^{-7}/y.

The 10^{-5}/y risk distance shows the spatial extent of a component since according to the Flemish risk criteria the individual risk outside the boundary of an establishment should be lower than 10^{-5}/y. The 10^{-6}/y and 10^{-7}/y risk distances are the required separation distances between the installation and respectively a residential area and a vulnerable location.

3.2 Risk distances of installations and activities, excluding transport

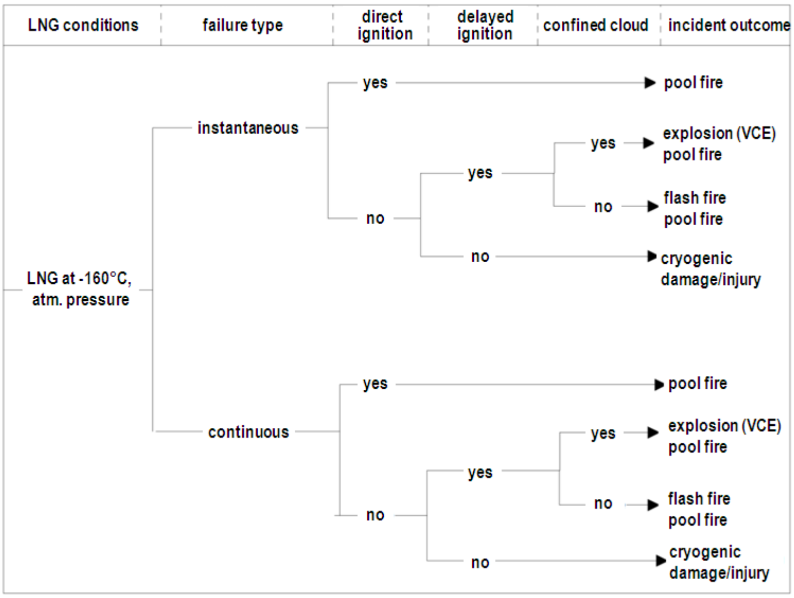
FAILURE MODES – The failure modes that are studied for installations and activities, excluding the transport of dangerous substances, are taken from the Handbook Failure Frequencies 2009 from the Flemish government [1].

For atmospheric tanks and pressure tanks, the generic failure modes are the instantaneous rupture of the tank, the outflow of the complete inventory of the tank within 10 minutes, a large leak (typically resulting from the rupture of the largest liquid connection), a medium-sized leak (with a diameter of 25 mm) and a small leak (with a diameter of 10 mm).

For flexible hoses and fixed arms, the generic failure modes are a rupture and a leak. For loading and unloading activities, failure of blocking systems to prevent or limit an unwanted release are taken into account.

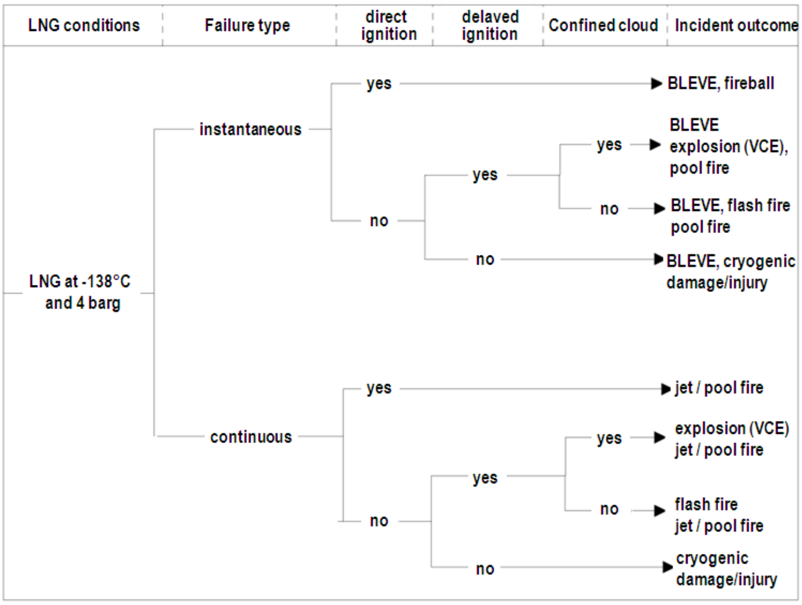
INCIDENT OUTCOMES – The incident outcomes that may occur following a release of liquefied methane (LNG) stored at atmospheric pressure are given in figure 3.2.1. They include a pool fire, a flash fire and a vapour cloud explosion (VCE).

Figure 3.2.1: Event tree for a release of LNG stored at atmospheric pressure



If the LNG is stored at a pressure substantially above atmospheric pressure, it will partially flash (rapidly evaporate) upon release. This may lead to additional incident outcomes, namely a BLEVE (boiling liquid expanding vapour explosion), a fire ball and a jet fire.

Figure 3.2.2: Eevent tree for a release of LNG stored at a pressure substantially above atmospheric pressure



FAILURE FREQUENCIES AND INCIDENT OUTCOME PROBABILITIES – The failure frequencies and incident outcome probabilities that are applied in the QRA are taken from the Handbook Failure Frequencies 2009 [1].

RISK DISTANCES – For installations other than atmospheric storage tanks, the LNG can be present at temperatures above the normal boiling point (-160℃) – and at pressures above atmospheric pressure. For these installations, the risk distances are calculated for LNG at -160℃ and at -138℃.

Some of the calculated risk distances are given in tables 3.2.1 to 3.2.4.

Table 3.2.1: Calculated risk distances for atmospheric storage tanks (-160°C)

Tank type and storage capacity		Tank without a bund			Tank within a bund		
		10^{-5}/y	10^{-6}/y	10^{-7}/y	10^{-5}/y	10^{-6}/y	10^{-7}/y
Single-walled tank	10,000 m^3	*not calculated*			176 m	216 m	230 m
	20,000 m^3				228 m	298 m	332 m
	40,000 m^3				286 m	360 m	448 m
Double-walled tank	10,000 m^3	16 m	92 m	148 m	16 m	92 m	148 m
	20,000 m^3	16 m	94 m	158 m	16 m	92 m	156 m
	40,000 m^3	16 m	102 m	166 m	16 m	102 m	166 m
Full-containment tank		individual risk level < 10^{-7}/y			individual risk level < 10^{-7}/y		

Table 3.2.2: Calculated risk distances for vacuum-insulated pressure tanks (-138 to -160°C)

Storage capacity	Tank(s) without a bund			Tank(s) within a bund		
	10^{-5}/y	10^{-6}/y	10^{-7}/y	10^{-5}/y	10^{-6}/y	10^{-7}/y
500 m^3	-	4 m	164 m	-	4 m	122 m
700 m^3	-	6 m	196 m	-	6 m	142 m
1,000 m^3 (2x 500 m^3)	-	44 m	228 m	-	40 m	222 m
1,500 m^3 (3x 500 m^3)	-	72 m	282 m	-	70 m	282 m
2,100 m^3 (3x 700 m^3)	-	102 m	326 m	-	90 m	326 m
3,500 m^3 (5x 700 m^3)	-	148 m	376 m	-	114 m	376 m

Table 3.2.3: Calculated risk distances for the (un)loading of ships via arms (-138 to -160°C)

Type of arm and operating time (h/y)		Without an ESD system			Manual ESD system			Automatic ESD system		
		10^{-5}/y	10^{-6}/y	10^{-7}/y	10^{-5}/y	10^{-6}/y	10^{-7}/y	10^{-5}/y	10^{-6}/y	10^{-7}/y
4" (200 m^3/h)	250 h/y	-	18 m	60 m	-	16 m	60 m	-	16 m	60 m
	500 h/y	4 m	30 m	70 m	-	28 m	70 m	-	28 m	70 m
	1,000 h/y	8 m	44 m	92 m	8 m	44 m	80 m	8 m	44 m	80 m
	2,000 h/y	16 m	56 m	124 m	14 m	56 m	90 m	14 m	56 m	88 m
8" (1000 m^3/h)	250 h/y	-	66 m	164 m	-	66 m	138 m	-	64 m	136 m
	500 h/y	10 m	90 m	216 m	10 m	90 m	164 m	10 m	90 m	162 m
	1,000 h/y	24 m	110 m	318 m	24 m	110 m	214 m	24 m	110 m	214 m
	2,000 h/y	58 m	154 m	430 m	56 m	132 m	282 m	54 m	132 m	282 m
14" (3000 m^3/h)	250 h/y	10 m	112 m	300 m	10 m	110 m	220 m	10 m	110 m	216 m
	500 h/y	26 m	144 m	376 m	24 m	144 m	278 m	24 m	144 m	278 m
	1,000 h/y	44 m	178 m	578 m	42 m	176 m	434 m	42 m	176 m	434 m
	2,000 h/y	98 m	280 m	702 m	94 m	208 m	566 m	94 m	206 m	566 m

Table 3.2.4: Calculated risk distances for LNG bunkering via hoses (-138 to -160 °C) (*)

Type of hose and operating time (h/y)		Without an ESD system			Manual ESD system			Automatic ESD system		
		10^{-5}/y	10^{-6}/y	10^{-7}/y	10^{-5}/y	10^{-6}/y	10^{-7}/y	10^{-5}/y	10^{-6}/y	10^{-7}/y
2x 2” (50 m^3/h)	250 h/y	16 m	42 m	72 m	14 m	30 m	46 m	14 m	30 m	42 m
	500 h/y	20 m	50 m	74 m	18 m	36 m	50 m	16 m	34 m	44 m
	1,000 h/y	28 m	56 m	76 m	24 m	40 m	56 m	24 m	38 m	48 m
	2,000 h/y	38 m	66 m	96 m	30 m	44 m	66 m	28 m	40 m	50 m
2x 6” (500 m^3/h)	250 h/y	48 m	98 m	258 m	46 m	86 m	120 m	46 m	86 m	120 m
	500 h/y	60 m	134 m	260 m	60 m	98 m	144 m	60 m	98 m	144 m
	1,000 h/y	72 m	170 m	262 m	72 m	108 m	170 m	72 m	104 m	150 m
	2,000 h/y	86 m	256 m	264 m	84 m	118 m	256 m	82 m	114 m	154 m
2x 12” (3000 m^3/h)	250 h/y	126 m	390 m	546 m	126 m	252 m	504 m	126 m	252 m	504 m
	500 h/y	186 m	496 m	552 m	154 m	324 m	510 m	154 m	324 m	510 m
	1,000 h/y	232 m	534 m	554 m	188 m	448 m	534 m	182 m	448 m	514 m
	2,000 h/y	330 m	542 m	558 m	226 m	498 m	542 m	226 m	498 m	514 m

(*) *The calculated risk distances are valid for shore-to-ship bunkering (via pipeline) or ship-to-ship bunkering activities. The risk associated with a loss of containment from the cargo system of the bunker ship is however not taken into account. This risk is calculated separately in section III.5 of the main report ‘risk analysis of the transport of LNG by water’.*

For the storage of LNG, the maximum uniform population density for which the societal risk criteria are not exceeded is calculated (tables 3.2.5 and 3.2.6).

Table 3.2.5: Maximum allowable population density around atmospheric tanks

Tank type and storage capacity		Maximum allowable population density with respect to the societal risk criterion
Single-walled tank with a bund	10,000 m^3	10.4 pers/ha
	20,000 m^3	5.9 pers/ha
	40,000 m^3	3.5 pers/ha
Double-walled tank or full-containment tank without a bund	10,000 m^3	6.0 pers/ha
	20,000 m^3	4.5 pers/ha
	40,000 m^3	2.3 pers/ha

Table 3.2.6: Maximum allowable population density around pressure tanks

Storage capacity	Maximum allowable population density with respect to the societal risk criterion
500 m^3	32 pers/ha
700 m^3	24 pers/ha
1,000 m^3 (2x 500 m^3)	32 pers/ha
1,500 m^3 (3x 500 m^3)	32 pers/ha
2,100 m^3 (3x 700 m^3)	24 pers/ha
3,500 m^3 (5x 700 m^3)	24 pers/ha

3.3 Risk distances for transport of LNG by road

The transport of LNG by means of single-walled trucks insulated with polyurethane foam and double-walled vacuum-insulated trucks is studied for a typical capacity of 50 m³ (ca. 19 metric tonne LNG).

FAILURE MODES – In case of a severe road traffic accident involving an LNG truck, three failure modes are studied. These are the instantaneous rupture of the tank and the continuous release from a hole with a diameter of 50 mm immediately after the accident, and the instantaneous rupture of the tank following a large-scale fire at the site of the accident.

INCIDENT OUTCOMES – The incident outcomes following an instantaneous or continuous release of LNG from a truck are the same as those for stationary storage tanks (see figures 3.2.1 and 3.2.2).

FAILURE FREQUENCIES AND INCIDENT OUTCOME PROBABILITIES – The annual frequency of a road traffic accident involving an LNG truck is estimated based upon statistical data of road traffic accidents with casualties involving a truck, while the incident outcome probabilities are estimated based upon literature data taking into account the type of road and the tank type.

RISK DISTANCES – Some of the calculated risk distances are given in tables 3.3.1 and 3.3.2. In general, the individual risk originating from the LNG transport by road is limited.

Table 3.3.1: Calculated risk distances for the road transport of cold LNG (-160°C)

Road type and annual number of transports		Single-walled trucks		Vacuum-insulated trucks	
		10^{-6}/y	10^{-7}/y	10^{-6}/y	10^{-7}/y
highway	500 trucks/y	-	-	-	-
	1,000 trucks/y	-	62 m	-	-
	2,000 trucks/y	-	88 m	-	-
	4,000 trucks/y	-	104 m	-	-
regional road with one lane in each direction	500 trucks/y	-	38 m	-	-
	1,000 trucks/y	-	60 m	-	-
	2,000 trucks/y	-	76 m	-	-
	4,000 trucks/y	22 m	88 m	-	22 m
regional road with two lanes in each direction	500 trucks/y	-	64 m	-	-
	1,000 trucks/y	-	88 m	-	-
	2,000 trucks/y	-	104 m	-	-
	4,000 trucks/y	52 m	118 m	-	52 m

Table 3.3.2: Calculated risk distances for the road transport of warm LNG (-138°C)

Road type and annual number of transports		Single-walled trucks		Vacuum-insulated trucks	
		10^{-6}/y	10^{-7}/y	10^{-6}/y	10^{-7}/y
highway	500 trucks/y	-	42 m	-	-
	1,000 trucks/y	-	82 m	-	-
	2,000 trucks/y	-	104 m	-	-
	4,000 trucks/y	14 m	122 m	-	14 m

Road type and annual number of transports		Single-walled trucks		Vacuum-insulated trucks	
		10^{-6}/y	10^{-7}/y	10^{-6}/y	10^{-7}/y
regional road with one lane in each direction	500 trucks/y	-	72 m	-	-
	1,000 trucks/y	-	92 m	-	-
	2,000 trucks/y	-	108 m	-	-
	4,000 trucks/y	62 m	122 m	-	62 m
regional road with two lanes in each direction	500 trucks/y	-	84 m	-	-
	1,000 trucks/y	-	104 m	-	-
	2,000 trucks/y	22 m	122 m	-	22 m
	4,000 trucks/y	76 m	144 m	-	76 m

3.4 Risk distances for transport of LNG by water

The individual risk originating from the presence of LNG (feeder and bunker) ships in the port is calculated for five different types of ship with capacities ranging from 800 to 30,000 m^3.

FAILURE MODES – A distinction is made between accidents that occur while the ship moves through the port and accidents that occur while the ship is moored.

For accidents involving moving ships, four failure modes are studied. These are the continuous release from a hole with a diameter of 1,000 mm and 150 mm following a ship-ship collision and the continuous release from a hole with a diameter of 150 mm and 75 mm following the collision of a ship with a stationary object.

For accidents involving moored ships, the five failure modes for stationary tanks described in §3.2 are studied. In addition, two failure modes following a ship-ship collision are studied. These are the continuous release from a hole of 150 mm and 75 mm.

INCIDENT OUTCOMES – The incident outcomes following an instantaneous or continuous release of LNG from a ship are the same as those for stationary storage tanks (see figures 3.2.1 and 3.2.2).

FAILURE FREQUENCIES AND INCIDENT OUTCOME PROBABILITIES – The annual frequency of collisions involving LNG ships is based upon literature data taking into account the traffic intensity, while the incident outcome probabilities are estimated based upon those of the Handbook Failure Frequencies while allowing for a higher probability of direct ignition following a collision.

RISK DISTANCES – Some of the calculated risk distances are given in tables 3.4.1 and 3.4.2. The individual risk originating from LNG vessels moving in the port is limited, whereas that originating from moored LNG vessels at an unprotected jetty or quay(2) is considerably higher because of the prolonged presence of the ship at a specific location.

---

(2) The calculated risk distances are only valid for LNG vessels which are moored at quays or jetties along the main waterways. If a LNG vessel is berthed in a dock, the likelihood of a collision is significantly lower.

Table 3.4.1: Calculated risk distances for ships which are in transit (-138 to -160°C)

Ship type and annual number of visits		Low traffic intensity (10,000 passages/year)			High traffic intensity (50,000 passages/year)			Very high traffic intensity (100,000 passages/year)		
		10^{-5}/y	10^{-6}/y	10^{-7}/y	10^{-5}/y	10^{-6}/y	10^{-7}/y	10^{-5}/y	10^{-6}/y	10^{-7}/y
3,000 m³	50 visits/year	-	-	34 m	-	2 m	76 m	-	34 m	108 m
	100 visits/year	-	-	50 m	-	34 m	108 m	-	50 m	162 m
	200 visits/year	-	-	70 m	-	50 m	162 m	-	70 m	224 m
7,500 m³	50 visits/year	-	-	34 m	-	2 m	76 m	-	34 m	110 m
	100 visits/year	-	-	50 m	-	34 m	110 m	-	50 m	164 m
	200 visits/year	-	-	70 m	-	50 m	164 m	-	70 m	224 m
30,000 m³	50 visits/year	-	-	34 m	-	2 m	76 m	-	34 m	110 m
	100 visits/year	-	-	50 m	-	34 m	110 m	-	50 m	164 m
	200 visits/year	-	-	72 m	-	50 m	164 m	-	72 m	226 m

Table 3.4.2: Calculated risk distances for ships moored at a jetty or quay (-138 to -160°C)

Ship type and annual number of visits		Low traffic intensity (10,000 passages/year)			High traffic intensity (50,000 passages/year)			Very high traffic intensity (100,000 passages/year)		
		10^{-5}/y	10^{-6}/y	10^{-7}/y	10^{-5}/y	10^{-6}/y	10^{-7}/y	10^{-5}/y	10^{-6}/y	10^{-7}/y
3,000 m³	50 visits/year	24 m	66 m	150 m	52 m	94 m	228 m	66 m	138 m	240 m
	100 visits/year	40 m	74 m	204 m	66 m	140 m	244 m	72 m	172 m	248 m
	200 visits/year	50 m	86 m	240 m	72 m	174 m	250 m	78 m	216 m	250 m
7,500 m³	50 visits/year	30 m	70 m	170 m	58 m	110 m	234 m	68 m	152 m	244 m
	100 visits/year	44 m	74 m	224 m	68 m	156 m	248 m	74 m	192 m	250 m
	200 visits/year	52 m	102 m	272 m	74 m	198 m	324 m	92 m	224 m	354 m
30,000 m³	50 visits/year	38 m	72 m	238 m	64 m	138 m	248 m	72 m	172 m	250 m
	100 visits/year	48 m	88 m	520 m	72 m	176 m	526 m	76 m	216 m	530 m
	200 visits/year	60 m	150 m	694 m	76 m	224 m	694 m	118 m	238 m	694 m

4. References

[1] *Handboek Faalfrequenties voor het opstellen van een veiligheidsrapport*, Vlaamse Overheid, Departement LNE, Afdeling Milieu-, Natuur- en Energiebeleid, Dienst Veiligheidsrapportering, 05/05/2009.

[2] *Achtergronddocument RBM II, versie 1.2,* Adviesgroep AVIV, in opdracht van het Ministerie van Verkeer en Waterstaat (Nl), maart 2008.

[3] *Risk Assessment Data Directory - Land transport accident statistics,* Report No. 434 – 9, International Association of Oil & Gas Producers, march 2010.

[4] *PGS3 Guidelines for quantitative risk assessment (purple book), Publicatiereeks Gevaarlijke Stoffen,* Ministerie van VROM, Nederland, 2005.

[5] *A quantitative risk analysis approach to port hydrocarbon logistics*, Ronza A., Carol S. et al., Journal of Hazardous Materials, volume A128, 2006.

[6] *Canvey: an investigation of potential hazards from operations in the Canvey Island/Thurrock area*, Health and Safety Executive (UK), 1978.