omgevingsveiligheid
& risicoanalyse

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Risk analysis / Bunkering of alternative fuels in the port of Amsterdam

Project 224962
Date 31 March 2023

Client:
Port of Amsterdam
PO Box 19406
1000 GK Amsterdam

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Project	224962
Date	31 March 2023
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Version no.	1.1.1

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Contents

1 Introduction

In the coming years, changes are expected in the Amsterdam port area with regard to the bunkering of so-called new energy carriers. By means of creating bunkering locations, Port of Amsterdam wants to facilitate pioneers in new fuels, such as hydrogen and methanol. That is why Port of Amsterdam wants an external safety investigation to be conducted for the bunkering of a number of marine fuels and specifically for the truck-to-ship bunkering. This report provides insight into the external safety distances associated with the truck-to-ship bunkering of various new energy carriers in the port of Amsterdam.

The effects of the following 14 different scenarios have been calculated:

1. Bunkering of LNG (single)
2. Bunkering of LNG (T piece)
3. Bunkering of methanol
4. Bunkering of hydrogen gas
5. Bunkering of hydrogen liquid
6. Bunkering of ammonia (NH_3)
7. All fuels combined with LNG as single
8. All fuels combined with LNG T piece
9. All fuels combined, excl. NH_3 with LNG as single
10. All fuels combined, excl. NH_3 with LNG T piece
11. All fuels combined with LNG as single and degassing
12. All fuels combined with LNG T piece and degassing
13. All fuels combined, excl. NH_3 with LNG as single and degassing
14. All fuels combined, excl. NH_3 with LNG T piece and degassing

For the combined scenarios, the number of hours of bunkering must be added together and this is the sum total of all the activities.

Chapter 2 sets out the basic principles of the risk calculations. Chapter 3 sets out the results of the location-related risk. Chapter 4, finally, sets out the conclusion.

2 Basic principles

2.1 Initial failure frequency

Table 1 shows the initial failure frequency for components of the installation as prescribed in the *Bevi* Risk Assessment Manual [1].

Component	Failure mode	Frequency
Tank truck	Instantaneous	5.0 10^{-7} /year
	Continuous largest connection	5.0 10^{-7} /year
	Pump (with gasket) breakage	1.0 10^{-4} /year
	Pump (with gasket) leakage	4.4 10^{-3} /year
	Unloading hose (composite) rupture	4.0 10^{-7} /hour
	Unloading hose (composite) leakage	4.0 10^{-5} /hour
	Unloading hose rupture	4.0 10^{-6} /hour
	Unloading hose leakage	4.0 10^{-5} /hour
	BLEVE due to fire during transshipment	5.8 10^{-10} /hour
Unloading hose to ship	Unloading hose (composite) rupture	4.0 10^{-7} /hour
	Unloading hose (composite) leakage	4.0 10^{-5} /hour
Atmospheric tank truck	Instantaneous	1.0 10^{-5} /year
	Continuous largest connection	5.0 10^{-7} /year
	Pump (with gasket) breakage	1.0 10^{-4} /year
	Pump (with gasket) leakage	4.4 10^{-3} /year
	Unloading hose rupture	4.0 10^{-6} /hour
	Unloading hose leakage	4.0 10^{-5} /hour
	Pool fire during transshipment	5.8 10^{-9} /hour

Table 1. Initial failure frequency of components of the installations

With regard to bunkering locations, the risk of external damage due to ship collisions should also be taken into account. These scenarios may be disregarded if the bunkering location is not situated along a through route. This is the case here [1] and that is why the risk of external damage need not be taken into account.

For a BLEVE of a tank truck caused by a fire in the surrounding area and by external impact, a methodology used for LNG filling stations is available [3]. The frequency used for a fire in the surrounding area and for the external impact due to a collision with another vehicle has been derived from that of a public filling station also used for refuelling with petrol. A bunkering location, however, is set up differently. The number of traffic movements at a bunkering location will be significantly smaller and measures will have been taken to limit the speed of the vehicles there. Also, no highly inflammable liquid such as petrol will be present there[1]. For a bunkering location, therefore, these frequencies cannot be applied. It has been assumed that these accident causes do not apply to a bunkering station. The Bevi Risk Assessment Manual does not explicitly prescribe these scenarios either [1].

2.2 LNG standalone

It has been assumed that bunkering is done by a double-walled insulated tank truck. The tank truck has a gross tank capacity of 60 m^3 and a maximum effective capacity of 50.5 m^3. The modelled throughput of LNG is 2000 m^3/year. The pressure is 0.66 bar(g) at a temperature of -155 ^oC. The pump flow rate is 500 l/min. During transshipment, the maximum pressure is 3 bar(g). This will result in an unloading time of 66.7 hours per year. It has been assumed that the tank truck stays 1.5 times as long at the bunkering location (a total of 100 hours, which is 1.1% of the year). Unloading takes place with a metal braided unloading hose[2]. If the pump breaks or the unloading hose ruptures, the truck driver can activate the emergency stop. In accordance with the calculation rule, the probability of success has been assumed to be equal to 0.9. In this case, outflow duration is limited to 120 s. Intervention has not been modelled for leakage of the pump or the unloading hose. The setting pressure of the tank truck's spring loaded pressure relief valve is 9 bar(g). A pressure of 11.1 bar(g) has been assumed for the BLEVE at increased pressure (this is 1.2 times the absolute setting pressure of the spring loaded pressure relief valve).

No account has been taken of any ESD system which might be present. An ESD system reduces the outflow duration in case of rupture of the unloading hose. Similarly, the risk of failure of the emergency stop would be less than 0.1. Conservatively, this measure has not been included in this risk analysis. The approach currently adopted may lead to an overestimation of the risk.

The pump flow rate is 500 l/min. On the basis of the conditions in the tank truck, this flow rate is equal to about 3.3 kg/s. If the unloading hose ruptures, outflow will occur for a short time with a source strength that depends on the conditions in the hose at the time of rupture. The hose is relatively short, so pump pressure falls off rapidly. It has been assumed that after that, outflow occurs with a source strength equal to the pump flow rate. This assumption is in line with the calculation rule. Provided, however, that the pre-pressure in the tank truck is less than 3.2 bar(g).

Rupture of the unloading hose can lead to backflow. On the basis of a 50 mm diameter filling pipe with a length of 15 m, the flow rate of the backflow is about 3.9 kg/s (calculated for a vapour pressure of 1.4 bar(g) and a liquid head of 4 m in the horizontally mounted storage tank on the ship). Activation of the emergency stop by the truck driver is taken into account (probability of success is 0.9 with an the outflow duration of 120 s); also taken into account is

[1] There is no simultaneous bunkering of LNG and, for instance, methanol.
[2] *RIVM* (the Dutch National Institute for Public Health and the Environment) has not yet derived any individual risks of failure for this type of hose. It has therefore been assumed that a standard unloading hose is being used.

the non-return valve at the storage tank (probability of success is 0.96 and duration of outflow 5 s). On the basis of these different outflow durations, it is necessary to formulate an approach as shown in the event tree below (the flow rate of the backflow during 5 s is spread over an effective exposure time of 20 s). This method is in line with the *Interim rekenmethode LNG-bunkerstations* (calculation method for LNG bunkering stations) [2].

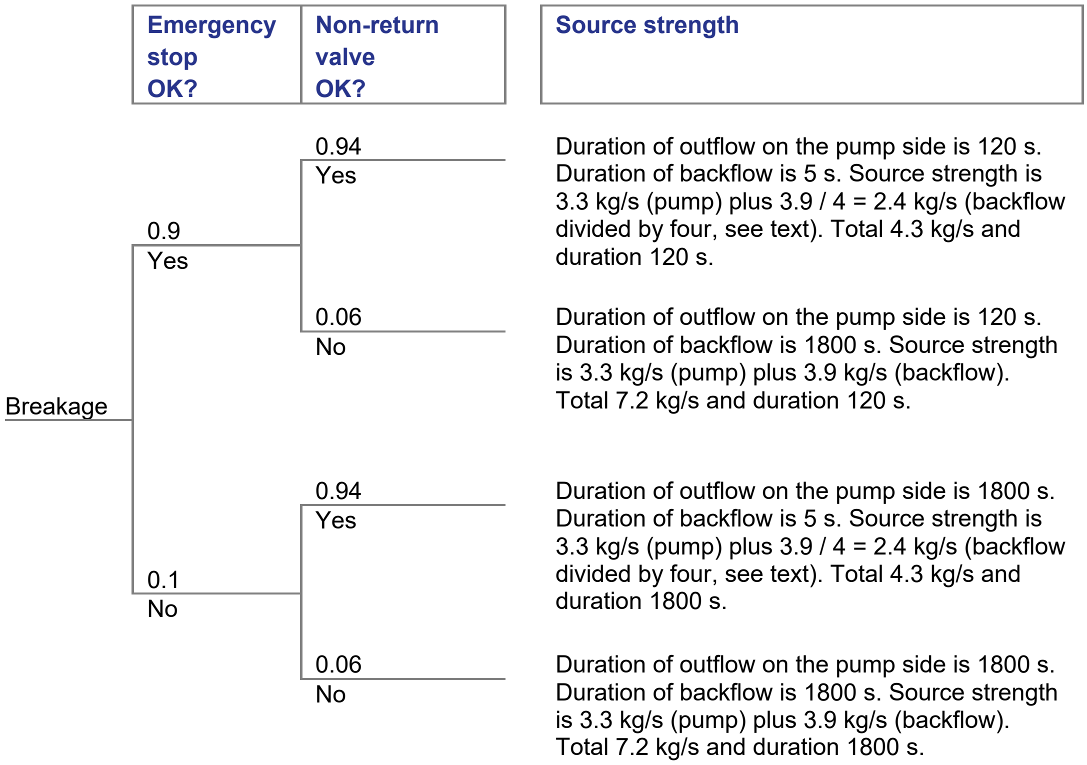


Table 2 shows the accident scenarios for the transshipment of LNG by tank truck. Unloading can take place both during the day and at night. It is assumed that unloading is proportional.

Scenario	Explanation of frequency
Instantaneous	0.011 (time fraction present) x 5.0 10^{-7} (frequency per year)
Continuous largest connection	0.011 (time fraction present) x 5.0 10^{-7} (frequency per year)
Pump breakage emergency stop OK	100 (hours in operation) /8760 (hours per year) x 1.0 10^{-4} (frequency of breakage per year in operation) x 0.9 (probability of emergency stop successful)
Pump breakage emergency stop not OK	100 (hours in operation) /8760 (hours per year) x 1.0 10^{-4} (frequency of breakage per year in operation) x 0.1 (probability of emergency stop unsuccessful)
Pump leakage	100 (hours in operation) /8760 (hours per year) x 4.4 10^{-3} (frequency leakage per year in operation)
Rupture unloading hose emergency stop OK non-return valve OK	100 (hours in operation) x 4.0 10^{-6} (frequency of rupture per hour in operation) x 0.9 (probability of emergency stop successful) x 0.94 (probability of non-return valve successful)

Scenario	Explanation of frequency
Rupture unloading hose emergency stop OK non-return valve not OK	100 (hours in operation) x 4.0 10^{-6} (frequency of rupture per hour in operation) x 0.9 (probability of emergency stop successful) x 0.06 (probability of non-return valve successful)
Rupture unloading hose emergency stop not OK non-return valve OK	100 (hours in operation) x 4.0 10^{-6} (frequency rupture per hour in operation) x 0.1 (probability emergency stop unsuccessful) x 0.94 (probability non-return valve successful)
Rupture unloading hose emergency stop not OK non-return valve not OK	100 (hours in operation) x 4.0 10^{-6} (frequency of rupture per hour in operation) x 0.1 (probability of emergency stop unsuccessful) x 0.06 (probability of non-return valve unsuccessful)
Leakage unloading hose	100 (hours in operation) x 4.0 10^{-5} (frequency of leakage per hour in operation)
BLEVE due to fire during unloading	100 (hours in operation) x 5.8 10^{-10} (frequency per hour in operation) x 0.05 (probability of BLEVE for a double-walled vacuum insulated tank truck)

Scenario	Frequency [/year]	Source strength	Explanation
Instantaneous	5.7 10^{-9}	20.8 tons	Maximum capacity
Continuous largest connection	5.7 10^{-9}	20.8 kg/s	Liquid 3-inch hole
Pump breakage emergency stop OK	1.0 10^{-6}	15.2 kg/s	Diameter 3", pipe 5 m, duration 120 s
Pump breakage emergency stop not OK	1.1 10^{-7}	15.2 kg/s	Diameter 3", pipe 5 m, duration 1300 s
Pump leakage	5.0 10^{-5}	0.2 kg/s	Liquid 7.5 mm hole, duration 1800 s
Rupture unloading hose emergency stop OK non-return valve OK	3.4 10^{-4}	4.3 kg/s	See text, duration 120 s
Rupture unloading hose emergency stop OK non-return valve not OK	2.2 10^{-5}	7.2 kg/s	See text, duration 120 s
Rupture unloading hose emergency stop not OK non-return valve OK	3.8 10^{-5}	4.3 kg/s	See text, duration 1800 s
Rupture unloading hose emergency stop not OK non-return valve not OK	2.4 10^{-6}	7.2 kg/s	See text, duration 1800 s
Leakage unloading hose	4.0 10^{-3}	0.21 kg/s	Liquid 5 mm hole, duration 1800 s
BLEVE due to fire during unloading	2.9 10^{-9}	20.8 tons	Maximum capacity, pressure 11.1 bar(g)

Table 2. Accident scenarios transshipment tank truck LNG standalone

2.3 LNG with T piece

For the LNG supply with a T piece, it has been assumed that the supply is done with two double-walled insulated tank trucks. The tank trucks each have a gross capacity of 60 m^3 and a maximum effective capacity of 50.5 m^3. The modelled throughput of LNG is 2000 m^3/year. The pressure is 0.66 bar(g) at a temperature of -155 °C. The pump flow rate is 333 l/min per tank truck. During transshipment, the maximum pressure is 3 bar(g). This results in an unloading time of 100 hours per year (50 hours per year for each of the two tank truck positions). It has been assumed that the tank trucks stay 1.5 times as long at the bunkering location (a total of 75 hours, which is 0.5% of the year for each of the two tank truck positions). Unloading takes place with a metal braided unloading hose[3]. If the pump breaks or the unloading hose ruptures, the truck driver can activate the emergency stop. In accordance with the calculation rule, the probability of success has been assumed to be equal to 0.9. In this case, outflow duration is limited to 120 s. Intervention has not been modelled for leakage of the pump or unloading hose. The setting pressure of the tank truck's spring loaded pressure relief valve is 9 bar(g). A pressure of 11.1 bar(g) has been assumed for the BLEVE at increased pressure (this is 1.2 times the absolute setting pressure of the spring loaded pressure relief valve).

This time, no account has been taken of the ESD system present. An ESD system reduces the outflow duration in case of rupture of the unloading hose. Similarly, the risk of failure of the emergency stop would be less than 0.1. Conservatively, this measure has not been included in this risk analysis. The approach currently adopted may lead to an overestimation of the risk.

The pump flow rate is equal to 667 l/min. On the basis of the conditions in the tank truck, this flow rate is equal to about 4.6 kg/s. If the unloading hose ruptures, outflow will occur for a short time with a source strength that depends on the conditions in the hose at the time of rupture. The hose is relatively short, so pump pressure falls off rapidly. It has been assumed that after that, outflow occurs with a source strength equal to the pump flow rate. This assumption is in line with the calculation rule. Provided, however, that the pre-pressure in the tank truck is less than 3.2 bar(g).

Rupture of the unloading hose between a tank truck and the T piece leads to outflow with the pump flow rate on either side of the rupture. There is no backflow from the tanks on the FlexFueler. This scenario has been modelled with a source strength of 9.2 kg/s.

Rupture of the unloading hose between the T piece and the FlexFueler could lead to backflow. On the basis of an 80 mm filling pipe with a length of 15 m, the flow rate of the backflow is about 9.7 kg/s (calculated for a vapour pressure of 1.4 bar(g) and a liquid head of 4 m in the horizontally mounted storage tank on the ship).

[3] *RIVM* (the Dutch National Institute for Public Health and the Environment) has not yet derived any individual risks of failure for this type of hose. It has therefore been assumed that a standard unloading hose is being used.

Activation of the emergency stop by the truck driver is taken into account (probability of success is 0.9 with an the outflow duration of 120 s); also taken into account is the non-return valve at the storage tank (probability of success is 0.96 and duration of outflow 5 s). On the basis of these different outflow durations, it is necessary to use an approach as formulated in the event tree below (the flow rate of the backflow during 5 s is spread over an effective exposure time of 20 s). This method is in line with the *Interim rekenmethode LNG-bunkerstations* (provisional calculation method for LNG bunkering stations) [2].

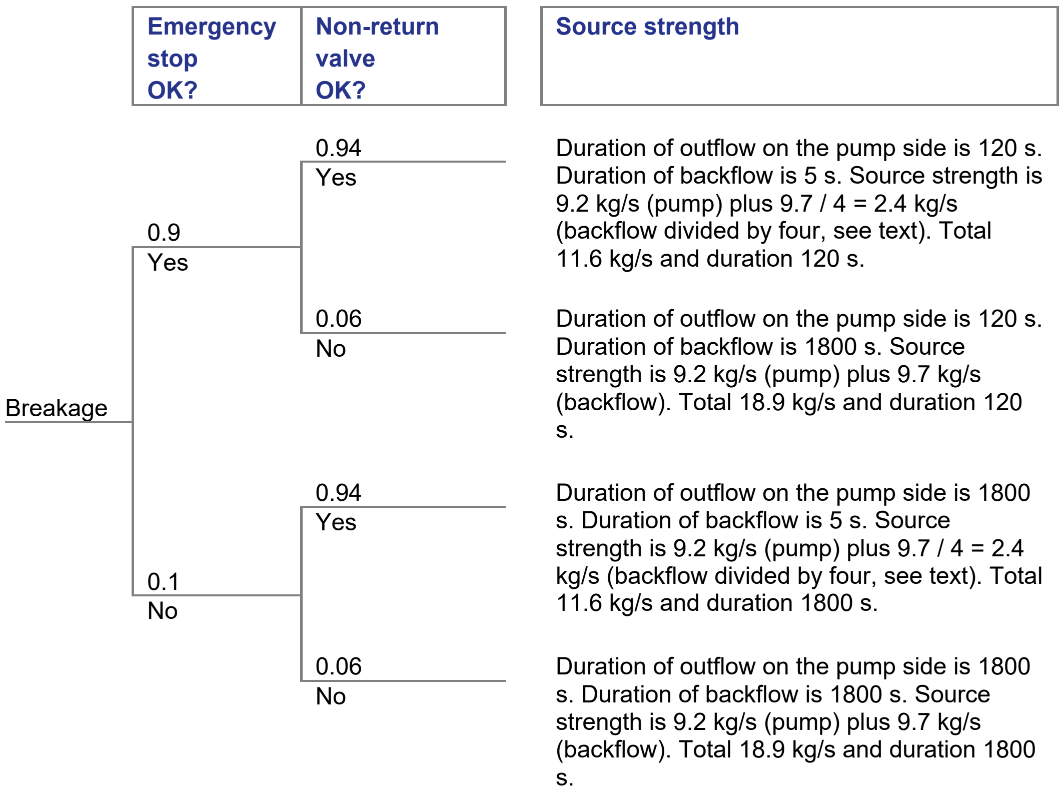


Table 3 shows the accident scenarios for the transshipment of LNG by tank truck with a T piece for each of the two positions of the tank truck. Table 4 shows the scenarios for the unloading hose between the T piece and the ship. Unloading can take place both during the day and at night. It is assumed that unloading is proportional.

Scenario	Explanation of frequency
Instantaneous	0.057 (time fraction present) x 5.0 10^{-7} (frequency per year)
Continuous largest connection	0.057 (time fraction present) x 5.0 10^{-7} (frequency per year)

Scenario	Explanation of frequency
Pump breakage emergency stop OK	50 (hours in operation) /8760 (hours per year) x 1.0 10^{-4} (frequency of breakage per year in operation) x 0.9 (probability of emergency stop successful)
Pump breakage emergency stop not OK	50 (hours in operation) /8760 (hours per year) x 1.0 10^{-4} (frequency of breakage per year in operation) x 0.1 (probability of emergency stop unsuccessful)
Pump leakage	50 (hours in operation) /8760 (hours per year) x 4.4 10^{-3} (frequency leakage per year in operation)
Rupture unloading hose emergency stop OK	50 (hours in operation) x 4.0 10^{-6} (frequency rupture per hour in operation) x 0.9 (probability of emergency stop successful)
Rupture unloading hose emergency stop not OK	50 (hours in operation) x 4.0 10^{-6} (frequency rupture per hour in operation) x 0.1 (probability of emergency stop unsuccessful)
Leakage unloading hose	50 (hours in operation) x 4.0 10^{-5} (frequency of leakage per hour in operation)
BLEVE due to fire during unloading	50 (hours in operation) x 5.8 10^{-10} (frequency per hour in operation) x 0.05 (probability of BLEVE for a double-walled vacuum insulated tank truck)

Scenario	Frequency [/year]	Source strength	Explanation
Instantaneous	2.9 10^{-9}	20.8 tons	Maximum capacity
Continuous largest connection	2.9 10^{-9}	20.8 kg/s	Liquid 3-inch hole
Pump breakage emergency stop OK	5.1 10^{-6}	15.2 kg/s	Diameter 3", pipe 5 m, duration 120 s
Pump breakage emergency stop not OK	5.7 10^{-7}	15.2 kg/s	Diameter 3", pipe 5 m, duration 1300 s
Pump leakage	2.5 10^{-5}	0.2 kg/s	Liquid 7.5 mm hole, duration 1800 s
Rupture unloading hose emergency stop OK	1.8 10^{-4}	9.2 kg/s	See text, duration 120 s
Rupture unloading hose emergency stop not OK	2.0 10^{-5}	9.2 kg/s	See text, duration 1800 s
Leakage unloading hose	2.0 10^{-3}	0.21 kg/s	Liquid 5 mm hole, duration 1800 s
BLEVE due to fire during unloading	1.5 10^{-9}	20.8 tons	Maximum capacity, pressure 11.1 bar(g)

Table 3. Accident scenarios transshipment tank truck with T piece for each tank truck position

Scenario	Explanation of frequency
Rupture unloading hose emergency stop OK non-return valve OK	50 (hours in operation) x 4.0 10^{-6} (frequency of rupture per hour in operation) x 0.9 (probability of emergency stop successful) x 0.94 (probability of non-return valve successful)

Scenario	Explanation of frequency
Rupture unloading hose emergency stop OK non-return valve not OK	50 (hours in operation) x 4.0 10^{-6} (frequency of rupture per hour in operation) x 0.9 (probability of emergency stop successful) x 0.06 (probability of non-return valve successful)
Rupture unloading hose emergency stop not OK non-return valve OK	50 (hours in operation) x 4.0 10^{-6} (frequency rupture per hour in operation) x 0.1 (probability emergency stop unsuccessful) x 0.94 (probability non-return valve successful)
Rupture unloading hose emergency stop not OK non-return valve not OK	50 (hours in operation) x 4.0 10^{-6} (frequency of rupture per hour in operation) x 0.1 (probability of emergency stop unsuccessful) x 0.06 (probability of non-return valve unsuccessful)
Leakage unloading hose	50 (hours in operation) x 4.0 10^{-5} (frequency of leakage per hour in operation)

Scenario	Frequency [/year]	Source strength	Explanation
Rupture unloading hose emergency stop OK non-return valve OK	1.7 10^{-4}	11.6 kg/s	See text, duration 120 s
Rupture unloading hose emergency stop OK non-return valve not OK	1.1 10^{-5}	18.9 kg/s	See text, duration 120 s
Rupture unloading hose emergency stop not OK non-return valve OK	1.9 10^{-5}	11.6 kg/s	See text, duration 1800 s
Rupture unloading hose emergency stop not OK non-return valve not OK	1.2 10^{-6}	18.9 kg/s	See text, duration 1800 s
Leakage unloading hose	2.0 10^{-3}	0.5 kg/s	Liquid 8 mm hole, duration 1800 s

Table 4. Accident scenarios hose between T piece and FlexFueler

2.4 Methanol

2.4.1 Description methanol installation

The methanol is transported by road by tank truck and pumped directly to the ship. A hose is used as a connection between the tank truck and the ship. It has been assumed that transshipment takes place with a standard atmospheric tank truck.

The modelled throughput of methanol is 3000 m^3/year. Assuming a density of 803.75 kg/m^3 (the density of methanol for a temperature of 10 °C and a pressure of 0 bar(g)), this equals 2411 tons/year. The delivery flow rate from a tank truck is 833 l/min. Thus, methanol delivery takes place for about 60 hours per year (this is 0.68% of the year).

2.4.2 Selection of components

The risk analysis has been carried out for the tank truck (including the pump and the unloading hose). No scenarios have been modelled for pipelines containing only gas (vapour return line). The impact of these scenarios is negligible.

The scenarios for the components of the installation are described in section 2.4.3. These are standard scenarios for components as prescribed in the Bevi Risk Assessment Manual [1]. These standard scenarios for components are shown in table 1.

2.4.3 Accident scenarios tank truck transshipment

Methanol throughput is 3000 m^3/year. It has been assumed that methanol is supplied by atmospheric tank truck. The tank truck has a gross capacity of 30 m^3. The pump flow rate is 833 l/min. This will result in an unloading time of 60 hours per year. It is assumed that the tank truck is at the bunkering location for 1.5 times as long (a total of 90 hours, which is 1.0% of the year). Unloading takes place with an unloading hose. If the pump breaks or the unloading hose ruptures, the truck driver can activate the emergency stop. In accordance with the calculation rule, the probability of success has been assumed to be equal to 0.9. In this case, outflow duration is limited to 120 s. Intervention has not been modelled for leakage of the pump or unloading hose.

The pump flow rate is 833 l/min. On the basis of the conditions in the tank truck, this flow rate is equal to about 11.2 kg/s. If the unloading hose ruptures, outflow will occur for a short time with a source strength that depends on the conditions in the hose at the time of rupture. The hose is relatively short, so pump pressure falls off rapidly. It has been assumed that after that, outflow occurs with a source strength equal to the pump flow rate.

It has been assumed that there will be no backflow from the ship if the pump breaks or the unloading hose ruptures. Table 5 shows the accident scenarios for methanol transshipment by tank truck. For the calculations, it has been assumed that unloading will only take place during the day.

Scenario	Explanation of frequency
Instantaneous	0.01 (time fraction present) x 5.0 10^{-7} (frequency per year)
Continuous largest connection	0.01 (time fraction present) x 5.0 10^{-7} (frequency per year)
Pump breakage emergency stop OK	60 (hours in operation) /8760 (hours per year) x 1.0 10^{-4} (frequency of breakage per year in operation) x 0.9 (probability of emergency stop successful)
Pump breakage emergency stop not OK	60 (hours in operation) /8760 (hours per year) x 1.0 10^{-4} (frequency of breakage per year in operation) x 0.1 (probability of emergency stop unsuccessful)
Pump leakage	60 (hours in operation) /8760 (hours per year) x 4.4 10^{-3} (frequency leakage per year in operation)

Scenario	Explanation of frequency
Rupture unloading hose emergency stop OK	60 (hours in operation) x 4.0 10^{-6} (frequency rupture per hour in operation) x 0.9 (probability of emergency stop successful)
Rupture unloading hose emergency stop not OK	60 (hours in operation) x 4.0 10^{-6} (frequency rupture per hour in operation) x 0.1 (probability of emergency stop unsuccessful)
Leakage unloading hose	60 (hours in operation) x 4.0 10^{-5} (frequency of leakage per hour in operation)
Pool fire during unloading	60 (hours in operation) x 5.8 10^{-10} (frequency per hour in operation)

Scenario	Frequency [/year]	Source strength	Explanation
Instantaneous	1.0 10^{-7}	24.1 tons	Maximum capacity
Continuous largest connection	5.1 10^{-9}	18.8 kg/s	Liquid 3-inch hole
Pump breakage emergency stop OK	6.2 10^{-7}	8.5 kg/s	Diameter 2", pipe 5 m, duration 120 s
Pump breakage emergency stop not OK	6.8 10^{-8}	8.5 kg/s	Diameter 2", pipe 5 m, duration 1800 s
Pump leakage	3.0 10^{-5}	0.1 kg/s	Liquid 5.7 mm hole, duration 1800 s
Rupture unloading hose emergency stop OK	2.2 10^{-4}	11.2 kg/s	See text, duration 120 s
Rupture unloading hose emergency stop not OK	2.4 10^{-5}	11.2 kg/s	See text, duration 1800 s
Leakage unloading hose	2.7 10^{-3}	0.1 kg/s	Liquid 5 mm hole, duration 1800 s
Pool fire during unloading	3.5 10^{-7}	24.1 tons	Maximum capacity, layer thickness 5mm

Table 5. Accident scenarios bunkering of Methanol

2.5 Hydrogen gas phase

The hydrogen is transported by road by gas cylinder battery trailer[4] and pumped directly to the ship. A hose is used as a connection between the tank truck and the ship.

The modelled throughput of hydrogen is 360 tons/year. It has been assumed that transshipment takes place with 500 kg per hour. Thus, hydrogen delivery takes place for about 720 hours per year. It has been assumed that the tank trucks spend 1.5 times as long at the bunkering location (a total of 1080 hours - this is 12.3% of a year).

[4] Bunkering can also be done with a tube trailer or a (swap) container. The normative scenario, hose rupture, is the same for all options so the risk contours of all options are the same.

For modelling purposes, it has been assumed that a gas cylinder battery trailer is used carrying 104 cylinders with 347 l capacity each. The pressure is 500 bar(g). About 1115 kg of hydrogen is supplied by one gas cylinder battery trailer. The probability of a fireball due to fire in the surrounding area of the trailer depends on the surrounding area. For this purpose, memo [4] provides a table with assessment distances. It has been assumed that the position lies outside the assessment distances. Operator intervention has not been taken into account as this does not change the location of the location-related risk contour 10^{-6}. This is because the risks of failure are too high. Table 6 shows the accident scenarios. For the outflow duration of the continuous scenarios, the total volume of one trailer has been used.

Scenario	Explanation of frequency
Instantaneous	(1080/8766) (hours per year present / hours per year) x104 (number of bottles) x 5.0 10^{-7} (frequency per year)
Continuous largest connection	(1080/8766) (hours per year present / hours per year) x 104 (number of bottles) x 5.0 10^{-7} (frequency per year)
Fireball fire during transshipment	720 (hours per year present) x 5.8 10^{-10} (frequency fireball per hour)
Hose rupture	720 (hours per year present) x 4.0 10^{-6} (frequency rupture per hour in operation)
Hose leakage	720 (hours per year present) x 4.0 10^{-5} (frequency leakage per hour in operation)

Scenario	Frequency [/year]	Source strength	Explanation
Instantaneous	6.4 10^{-6}	11.2 kg	Maximum capacity of one bottle
Continuous largest connection	6.4 10^{-6}	12.3 kg/s	Hole size 15 mm, outflow duration 91 s.
Fireball fire during transshipment	4.2 10^{-7}	11.2 kg	Maximum capacity of one bottle
Hose rupture	2.9 10^{-3}	12.3 kg/s	Hole size 15 mm, outflow duration 91 s.
Hose leakage	2.9 10^{-2}	0.12 kg/s	Hole size 1.5 mm, outflow duration 1800 s.

Table 6. Accident scenarios bunkering of hydrogen gas phase

2.6 Hydrogen liquid phase

The hydrogen is transported by road by tank truck and pumped directly to the ship. A cryogenic hose is used as a connection between the tank truck and the ship [4]. It has been assumed that bunkering is done by a double-walled insulated tank truck. The tank truck is present for 1 hour for the transshipment of 1500 kg and contains 45 m^3. The pressure is 4 bar(g) with a temperature of -246°C.

The modelled throughput of hydrogen is 5000 m^3/year. Assuming a density of 803.75 kg/m^3 (the density of hydrogen for a temperature of -246 °C and a pressure of 4 bar(g)), this is equivalent to 303 tons/year. Thus, hydrogen delivery takes place for approximately 202 hours per year. It has been assumed that the tank trucks spend 1.5 times as long at the bunkering location (a total of 303 hours - this is 3.4% of a year).

The trailer is connected to the installation with a hose. At present, it is unknown what type of hose will be used and therefore, as a conservative assumption, it has been assumed that the risks of failure are those of a standard hose. The internal diameter of the hose is 12 mm. Table 7 shows the accident scenarios.

Scenario	Explanation of frequency
Instantaneous	5.0 10^{-7} (frequency per year) x 0.034 (fraction present)
Continuous 10 mm	5.0 10^{-7} (frequency per year) x 0.034 (fraction present)
Hose rupture	202 (hours in operation) x 4.0 10^{-6} (frequency rupture per hour in operation)
Hose leakage	202 (hours in operation) x 4.0 10^{-5} (frequency leakage per hour in operation)
BLEVE during transshipment	202 (hours in operation) x 5.8 10^{-10} (frequency BLEVE per hour in operation) x 0.05 (reduction factor double-walled)

Scenario	Frequency [/year]	Source strength [kg/s]	Explanation
Instantaneous	1.7 10^{-8}	2727 kg	Maximum capacity
Continuous largest connection	1.7 10^{-8}	0.3 kg/s	Outflow time 1800 s.
Hose rupture	8.1 10^{-4}	0.3 kg/s	Hole size 12 mm, outflow duration 1800 s.
Hose leakage	8.1 10^{-3}	< 0.01 kg/s	Hole size 1.2 mm, outflow duration 1800 s.
BLEVE during transshipment	5.9 10^{-9}	2727 kg	BLEVE only during transshipment

Table 7. Accident scenarios bunkering of hydrogen liquid phase

2.7 Ammonia

The ammonia is transported by road by tank truck and pumped directly to the ship. A hose is used as a connection between the tank truck and the ship. It has been assumed that transshipment takes place using a standard pressure tank truck.

The modelled throughput of ammonia is 4000 m^3/year. Assuming a density of 623.89 kg/m^3 (the density of ammonia for a temperature of 10 ºC and a pressure of 5.1 bar(g)), this equals 2496 tons/year. The delivery flow rate from a tank truck is 500 l/min. Thus, ammonia delivery takes place for approximately 133 hours per year. It is assumed that the tank truck is at the bunkering location for 1.5 times as long (a total of 200 hours, which is 2.2% of a year). Unloading takes place with an unloading hose. If the pump breaks or the unloading hose ruptures, the truck driver can activate the emergency stop. In accordance with the calculation rule, the probability of success has been assumed to be equal to 0.9. In this case, outflow duration is limited to 120 s. Intervention has not been modelled for leakage of the pump or unloading hose.

The pump flow rate is 500 l/min. On the basis of the conditions in the tank truck, this flow rate is equal to about 5.2 kg/s. If the unloading hose ruptures, outflow will occur for a short time with a source strength that depends on the conditions in the hose at the time of rupture. The hose is relatively short, so pump pressure falls off rapidly. It has been assumed that after that, outflow occurs with a source strength equal to the pump flow rate.

It has been assumed that there will be no backflow from the ship if the pump breaks or the unloading hose ruptures. Table 8 shows the accident scenarios for the transshipment of ammonia by tank truck. For the calculations, it has been assumed that unloading will only take place during the day.

Scenario	Explanation of frequency
Instantaneous	0.01 (time fraction present) x 5.0 10^{-7} (frequency per year)
Continuous largest connection	0.01 (time fraction present) x 5.0 10^{-7} (frequency per year)
Pump breakage emergency stop OK	60 (hours in operation) /8760 (hours per year) x 1.0 10^{-4} (frequency of breakage per year in operation) x 0.9 (probability of emergency stop successful)
Pump breakage emergency stop not OK	60 (hours in operation) /8760 (hours per year) x 1.0 10^{-4} (frequency of breakage per year in operation) x 0.1 (probability of emergency stop unsuccessful)
Pump leakage	60 (hours in operation) /8760 (hours per year) x 4.4 10^{-3} (frequency leakage per year in operation)
Rupture unloading hose emergency stop OK	60 (hours in operation) x 4.0 10^{-6} (frequency rupture per hour in operation) x 0.9 (probability of emergency stop successful)
Rupture unloading hose emergency stop not OK	60 (hours in operation) x 4.0 10^{-6} (frequency rupture per hour in operation) x 0.1 (probability of emergency stop unsuccessful)
Leakage unloading hose	60 (hours in operation) x 4.0 10^{-5} (frequency of leakage per hour in operation)

Scenario	Frequency [/year]	Source strength	Explanation
Instantaneous	1.0 10^{-7}	24.1 tons	Maximum capacity
Continuous largest connection	5.1 10^{-9}	18.8 kg/s	Liquid 3-inch hole
Pump breakage emergency stop OK	6.2 10^{-7}	8.5 kg/s	Diameter 2", pipe 5 m, duration 120 s
Pump breakage emergency stop not OK	6.8 10^{-8}	8.5 kg/s	Diameter 2", pipe 5 m, duration 1800 s
Pump leakage	3.0 10^{-5}	0.1 kg/s	Liquid 5.7 mm hole, duration 1800 s
Rupture unloading hose emergency stop OK	2.2 10^{-4}	5.2 kg/s	See text, duration 120 s
Rupture unloading hose emergency stop not OK	2.4 10^{-5}	5.2 kg/s	See text, duration 1800 s
Leakage unloading hose	2.7 10^{-3}	0.1 kg/s	Liquid 5 mm hole, duration 1800 s

Table 8. Accident scenarios bunkering of ammonia

2.8 Degassing

In addition to bunkering activities, Port of Amsterdam also wants to gain insight into the external safety of the degassing of ships. Royal Haskoning DHV has prepared a report with scenarios to be used for this purpose [5]. This report assumes the continuous presence of a ship, as per [5]. The scenarios used and assumptions made by Royal Haskoning DHV are shown in [5].

2.9 Surrounding area

Figure 1 shows the location of one of the potential bunkering locations. This location was chosen by the client because of the high population density in the surrounding area. To calculate group risk, it is necessary to model the presence of people within the maximum distance to 1% probability of death. This distance is about 763 m from the bunkering location, see chapter 6. The figure shows the so-called hazard zone. The presence of persons was modelled using the BAG (Dutch Key Register of Addresses and Buildings) population service (accessed 17 November 2022). The data thus obtained have been incorporated into the Safeti-NL model (the green areas in Figure 1). These data have been supplemented by 2 additional areas (the orange areas in Figure 1). The Sonneborn site is modelled larger than specified, but with the same number of people as in the BAG population service.

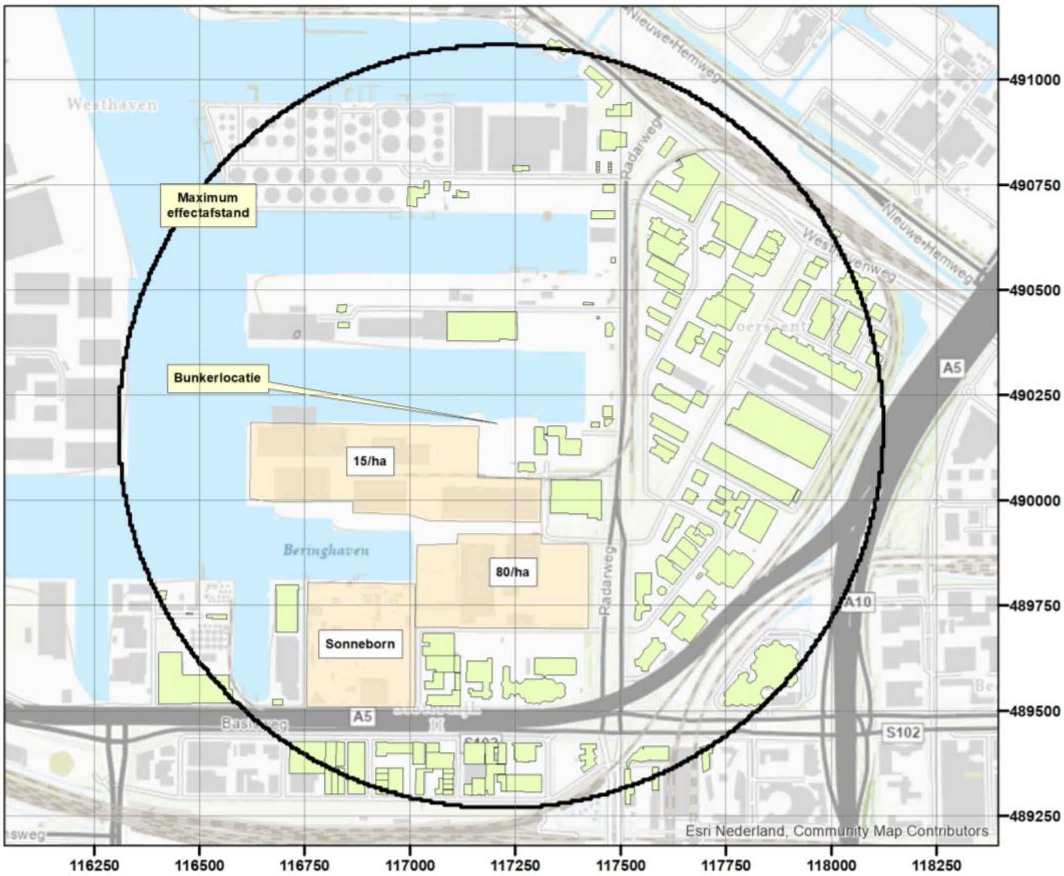


Figure 1. Example surrounding area of the bunkering location

2.10 Parameters

For the calculation, the default parameters of Safeti-NL version 8.5 have been used. The data for the Amsterdam Airport Schiphol weather station have been used for the probability of occurrence of a particular weather class. The default value of 0.3 m was used for the roughness length.

3 Location-related risk results

The location-related risk contours 10^{-5}, 10^{-6}, 10^{-7} en 10^{-8} /year for each scenario are shown in Annex 1. From these results, it can be concluded that the 10^{-6} contour is smallest for standalone methanol. The largest 10^{-6} contour follows from scenario 12. The distances are 22 and 93 metres respectively from the position of the tank trucks. Furthermore, it appears that all scenarios have relatively uniform10^{-6} contours, whereby for ammonia and LNG the influence of weather classes has more effect on the shape of the 10^{-6} contour than for methanol or hydrogen.

The location of the location-related risks 10^{-6} /year are mutually compared in this chapter. Figure 2 shows the location of this contour for each standalone (scenarios 1 to 6).

Figure 2 shows that the location-related risk contour 10^{-6} /year of methanol lies closest to the bunkering location. Incidentally, the model is based on dispersion over a hard surface. In reality, part of it will flow out into the water and mix with it. A pool fire on water is not possible. Furthermore, Figure 2 shows that the location-related risk contours10^{-6} /year of LNG with T piece and ammonia are furthest away from the bunkering location.

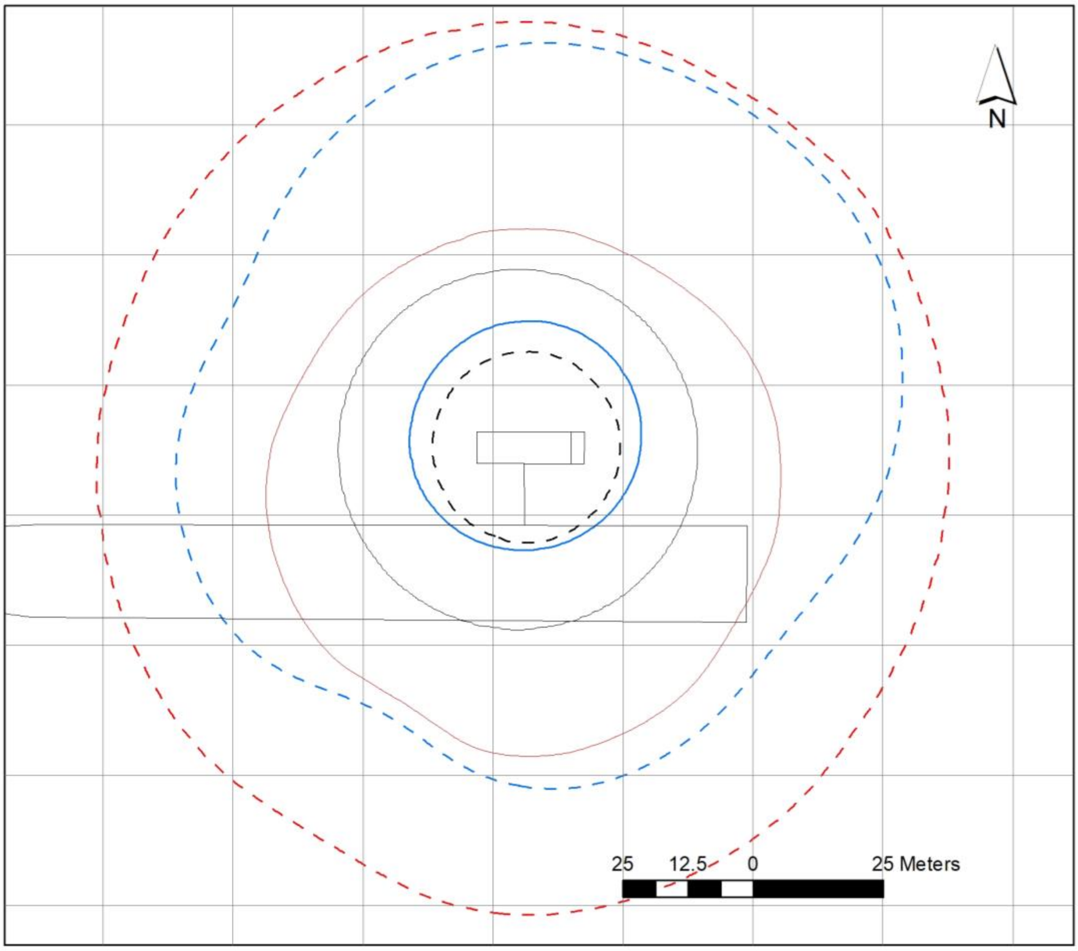


Figure 2. Comparison PR 10^{-6} contours standalone substances (PR means location-related risk)

1.0 10^{-6} /year Scenario 1 LNG Single
1.0 10^{-6} /year Scenario 2 LNG T piece
1.0 10^{-6} /year Scenario 3 Methanol
1.0 10^{-6} /year Scenario 4 Hydrogen gas phase
1.0 10^{-6} /year Scenario 5 Hydrogen Liquid
1.0 10^{-6} /year Scenario 6 Ammonia

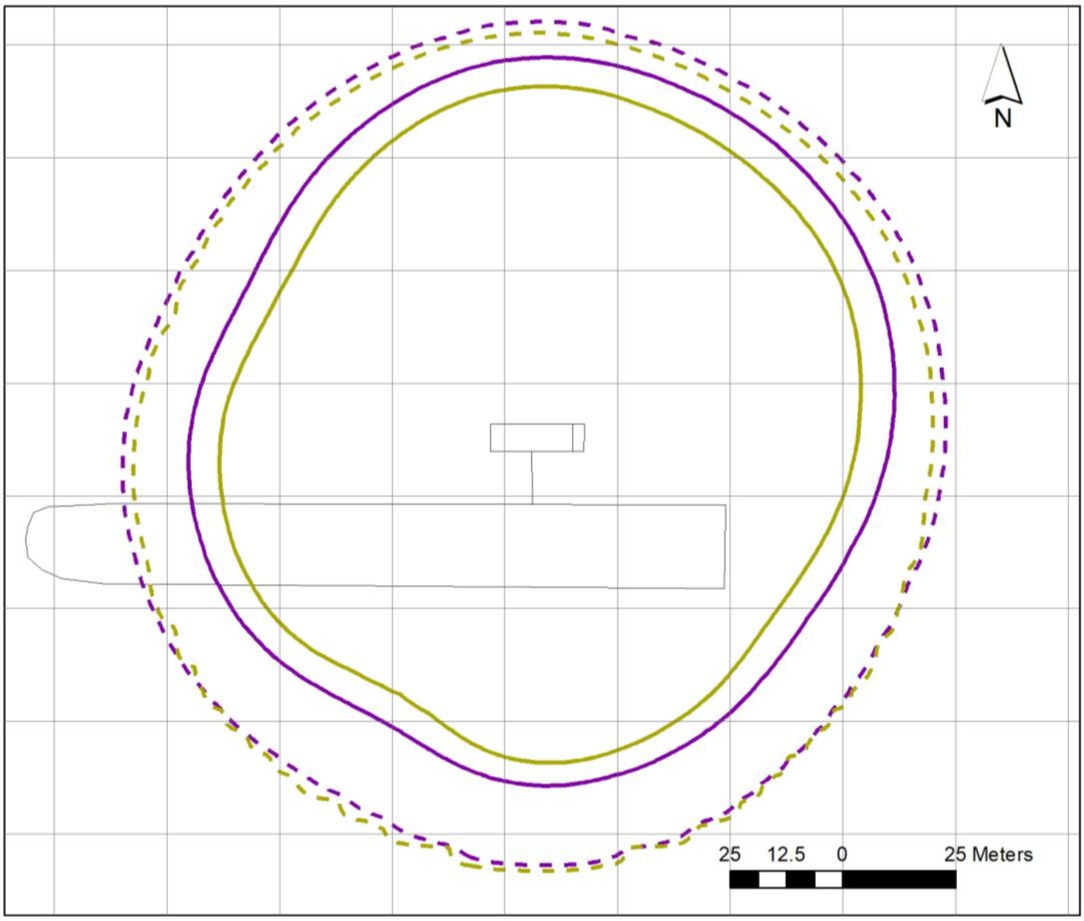


Figure 3. Comparison PR 10^{-6} contours scenarios 7, 8, 11 and 12

1.0 10^{-6} /year scenario 7 all combined with single LNG
1.0 10^{-6} /year scenario 8 all combined with LNG T piece
1.0 10^{-6} /year scenario 11 all combined with single LNG and degassing
1.0 10^{-6} /year scenario 12 all combined with LNG T piece and degassing

Figure 3 shows that even in the combined scenarios, bunkering of LNG with T piece leads to significantly larger distances compared to bunkering of LNG with a single tank truck. This figure also shows that degassing mainly contributes to the PR 10^{-6} contour if this contour lies closer to the bunkering location.

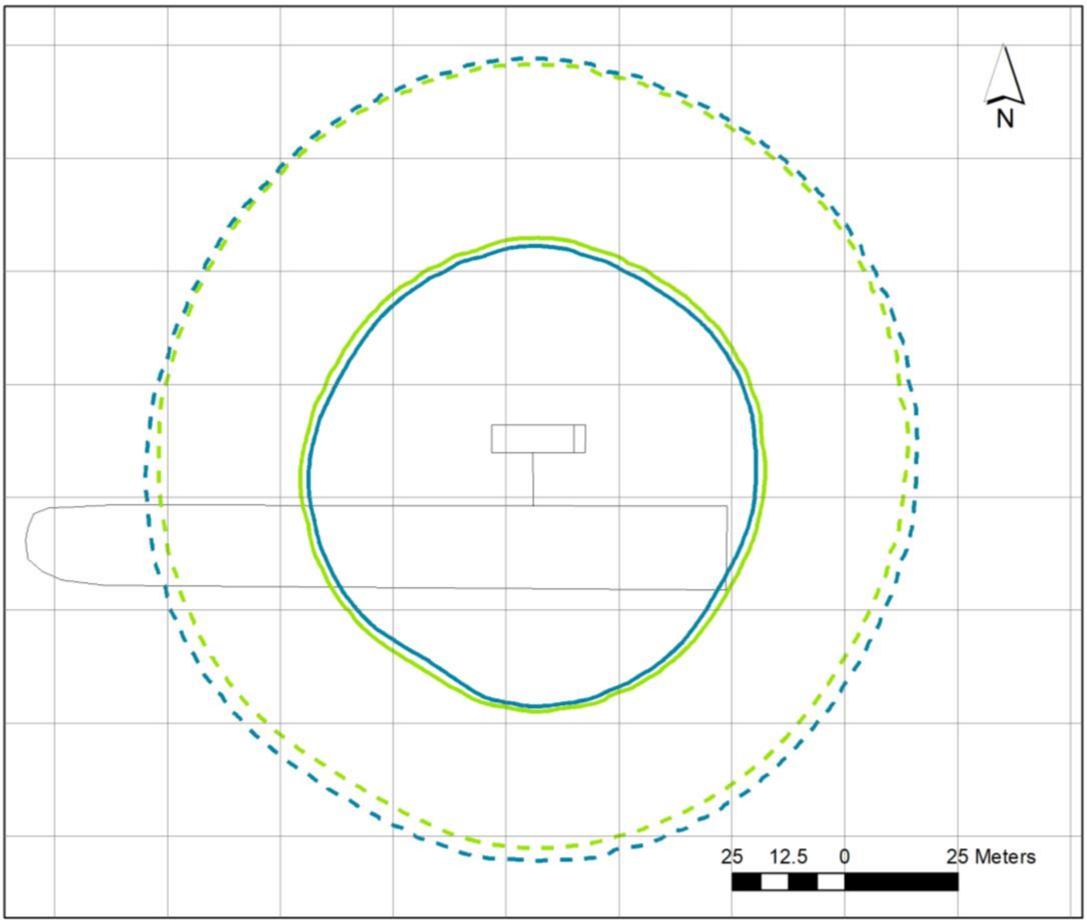


Figure 4. Comparison PR 10-6 contours scenarios 9, 10, 13 and 14

solid blue line	1.0 10^{-6} /year scenario 9 all combined, without NH_3 with single LNG
dashed blue line	1.0 10^{-6} /year scenario 10 all combined, without NH_3 with LNG T piece
solid green line	1.0 10^{-6} /year scenario 13 all combined, without NH_3 with single LNG and degassing
dashed green line	1.0 10^{-6} /year scenario 14 all combined, without NH_3 with LNG T piece and degassing

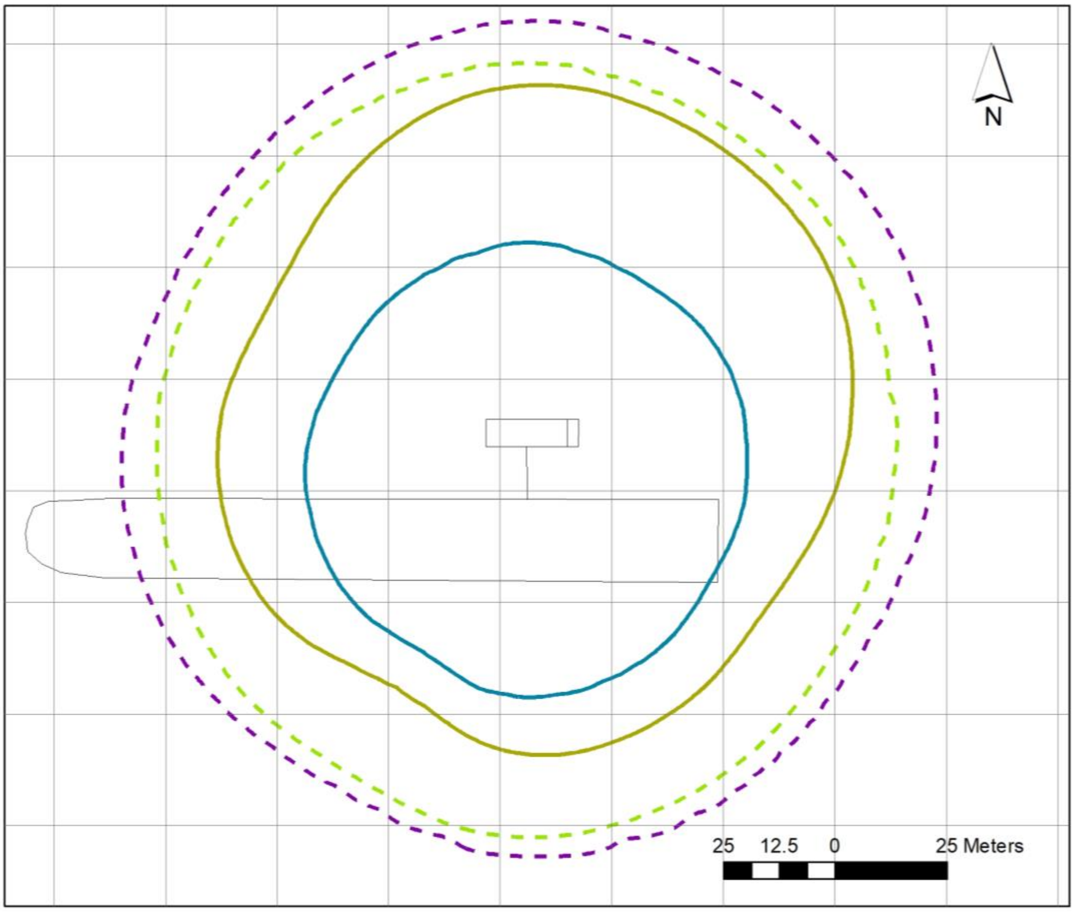


Figure 5. Comparison PR 10^{-6} contours scenarios 7, 9, 12 and 14

(solid olive line)	1.0 10^{-6} /year scenario 7 all combined with single LNG
(solid blue line)	1.0 10^{-6} /year scenario 9 all combined, without NH_3 with single LNG
(dashed purple line)	1.0 10^{-6} /year scenario 12 all combined with LNG T piece and degassing
(dashed green line)	1.0 10^{-6} /year scenario 14 all combined, without NH_3 with LNG T piece and degassing

4 Group risk results

This chapter mutually compares the location of the group risk curves. Figure 6 shows the location of this contour for each standalone (scenarios 1 to 6).

Figure 6 shows that only the bunkering of LNG with T piece and ammonia involves a clear group risk. For the other substances, the maximum number of casualties is less than 10. For both options with hydrogen and methanol, the group risk is so small that it cannot be shown on Figure 6. Group risk is below the orientation value in all cases.

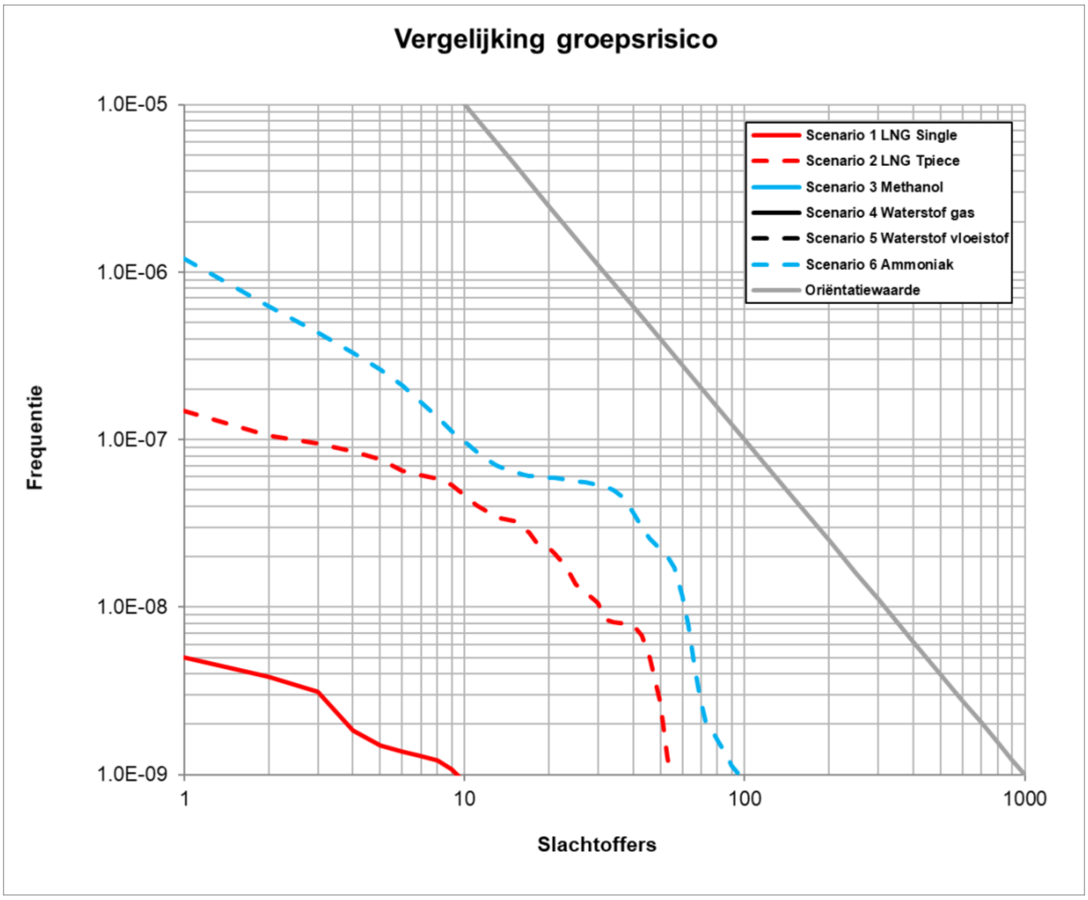


Figure 6. Group risk comparison standalone substances

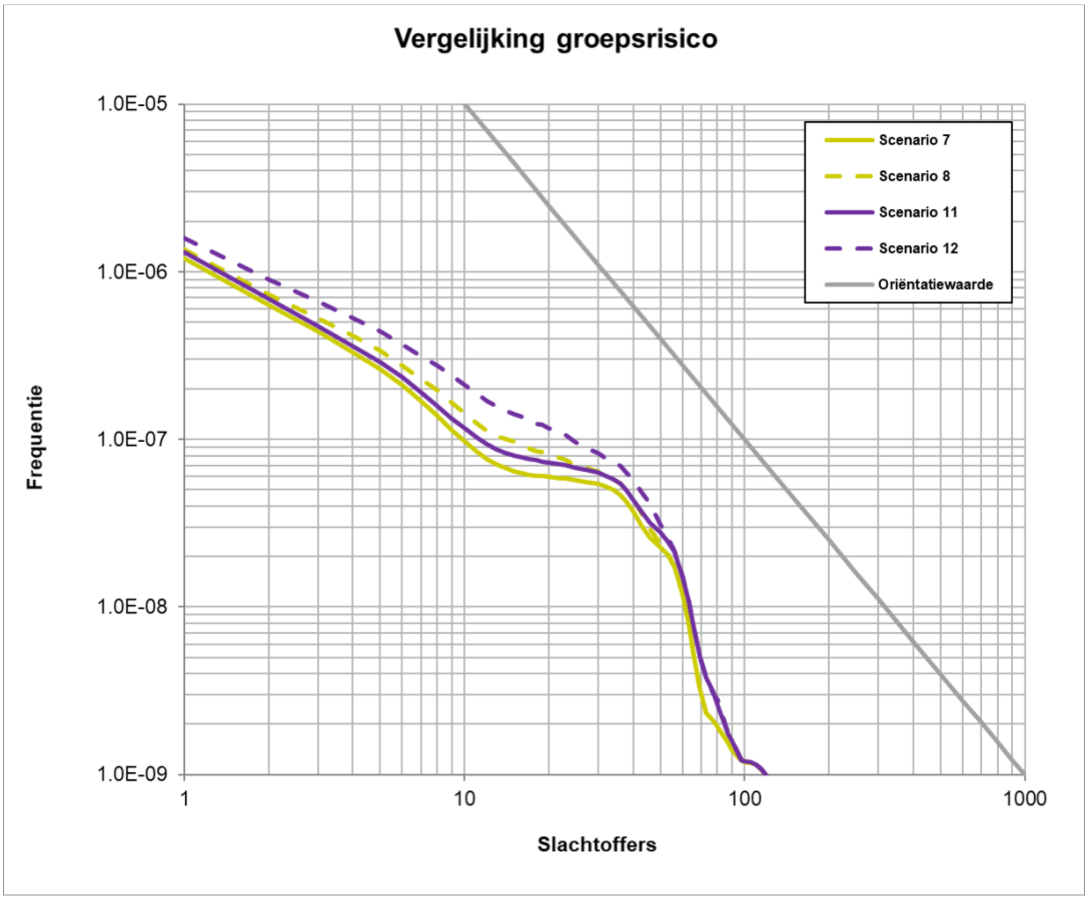


Figure 7. Comparison of group risk scenarios 7, 8, 11 and 12

Group risk scenario 7 all combined with single LNG
Group risk scenario 8 all combined with LNG T piece
Group risk scenario 11 all combined with single LNG and degassing
Group risk scenario 12 all combined with LNG T piece and degassing

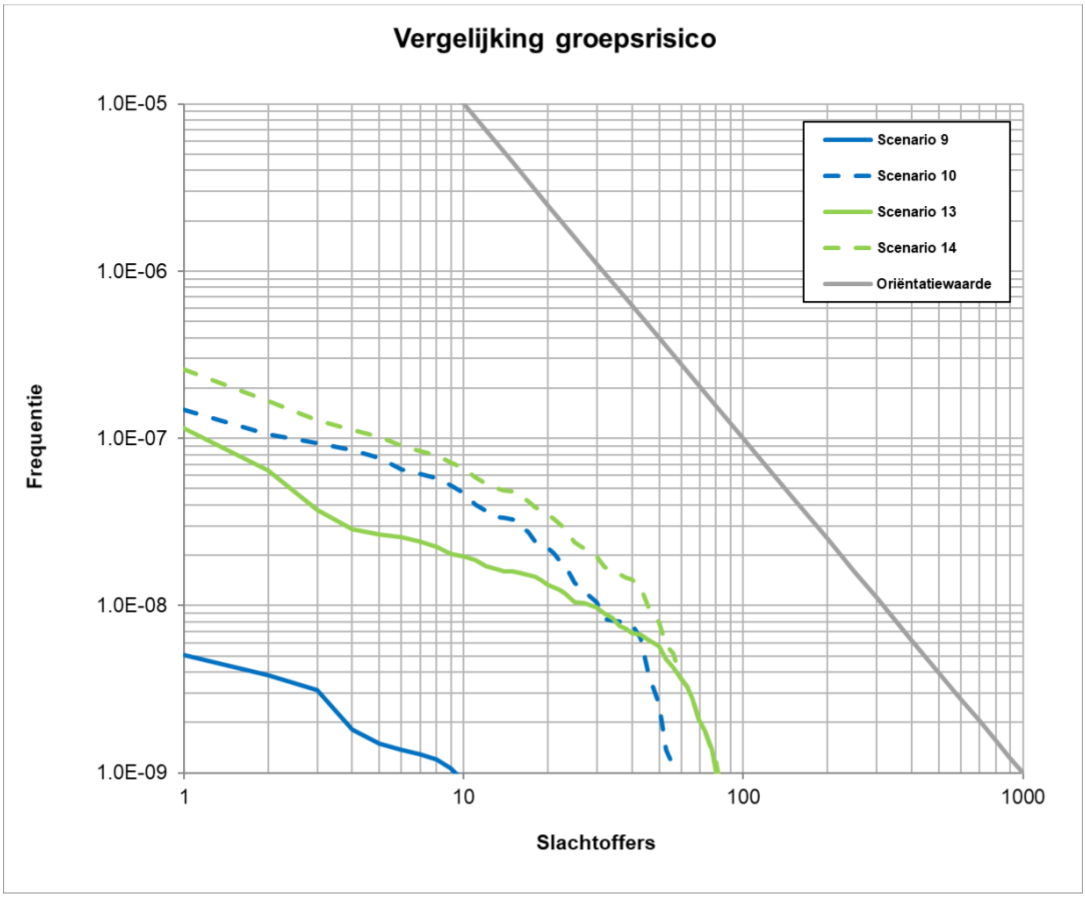
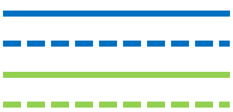


Figure 8. Comparison of group risk scenarios 9, 10, 13 and 14



Group risk scenario 9 all combined, without NH_3 with single LNG
Group risk scenario 10 all combined, without NH_3 with LNG T piece
Group risk scenario 13 all combined, without NH_3 with single LNG and degassing
Group risk scenario 14 all combined, without NH_3 with LNG T piece and degassing

5 Analysis of the results

5.1 Analysis of the location-related risk

The calculations show that the location-related risk contour 10^{-6} is smallest for methanol alone and largest for scenario 12 (combination with all substances, LNG with T piece and degassing). For methanol, the distance is about 22 metres from the bunkering location. Under scenario 12, this is about 94 metres. Table 9 shows the different scenarios and the maximum distance from the PR 10^{-6} contour.

Scenario	Distance [m]	Explanation
1	52	Bunkering of LNG (single)
2	83	Bunkering of LNG (T piece)
3	22	Bunkering of methanol
4	35	Bunkering of hydrogen gas
5	26	Bunkering of liquid hydrogen
6	78	Bunkering of ammonia
7	78	All fuels combined with LNG as single
8	92	All fuels combined with LNG T piece
9	48	All fuels combined, excl. NH_3 with LNG as single
10	93	All fuels combined, excl. NH_3 with LNG T piece
11	82	All fuels combined with LNG as single and degassing
12	94	All fuels combined with LNG T piece and degassing
13	54	All fuels combined, excl. NH_3 with LNG as single and degassing
14	87	All fuels combined, excl. NH_3 with LNG T piece and degassing

Table 9. Distances location-related risk contour 10^{-6}

From the table and figures above, it can be seen that bunkering of LNG with T piece and bunkering of ammonia make the largest contribution to the location of the 10^{-6} contour. In addition, it appears that degassing has some impact on the 10^{-6} contour. This contour is 'lifted' several metres.

The Annex shows all risk contours of the different options. The following becomes apparent:

- In all scenarios, except hydrogen, the PR 10^{-8} contour lies well away from the 10^{-6} contour. This is due to the relatively high risks of failure of the defining scenario, namely hose rupture 15mm. Under this scenario, the PR contours will be smaller if a narrower hose is used.
- All PR 10^{-6} contours are circular, except for LNG and for scenarios involving NH_3 and/or degassing. This is because pool fires and flares create circular effects that are hardly affected by different wind directions. During degassing and outflow of NH_3, toxic

substances are released as gas or evaporate from a pool. These toxic clouds are more weather dependent.

- Figure 3 shows that, even in the combined scenarios, bunkering LNG with T piece leads to significantly longer distances compared to bunkering LNG with a single tank truck. It can also be seen from this figure that degassing mainly contributes to the PR 10^{-6} contour if the contour lies closer to the bunkering location.

5.2 Analysis of the group risk

The results of the group risk calculations show that only the bunkering of LNG with T piece and NH_3 have significant impact on the group risk. All other substances lead to fewer than 10 casualties. Group risk lies below the orientation value in all cases.

When bunkering NH_3, the probability of multiple casualties is only higher than $4*10^{-8}$ for up to 40 casualties. The probability of more than 40 casualties is less than $4*10^{-8}$. This is due to the scenarios of instantaneous failure, largest connection, hose rupture (emergency stop not OK) and pump breakage (emergency stop not OK). The effects of the toxic cloud extend beyond those of the other scenarios (see Chapter 6). As a result, more people are exposed to these effects.

6 Impact distance

Impact distances were calculated for all scenarios. Table 10 shows the distance to 1% probability of death (with unprotected exposure) for weather class D-5.0 during the day and for weather class F-1.5 at night. The letter in the weather class shows the roughness of the weather. A is stormy; F is almost windless. The number represents the average wind speed in m/s. The Bevi Risk Assessment Manual prescribes that a QRA should show the 1% impact distances for these weather classes.

The designations in the columns 'component' and 'scenario' are a reference to the text in Chapter 2. The content of a cell is empty if no value is reported by Safeti-NL.

The criterion for the distance to 1% probability of death depends on the impact leading to the greatest distance for each scenario (e.g. 10 kW/m^2 for a flare lasting more than 20 s). For the impact distances of degassing, please refer to the relevant report.

Substance	**Component**	**Scenario**	**1% Death**	
			D-5.0 [m]	**F1.5 [m]**
LNG	Tank truck	Instantaneous	219	204
		ContinuousLargestConnection	103	145
		BreakagePumpEmergencystopOK	93	109
		BreakagePumpEmergencystopNot OK	93	128
		LeakagePump	14	17
		RuptureHoseEmergencystopOK	70	86
		RuptureHoseEmergencystopNotOK	70	96
		LeakageHose	6	1
		BLEVE during transshipment	199	200
	T piece to ship	RuptureHoseEmergencystopOK Non-returnvalveOK	71	88
		RuptureHoseEmergencystopOK Non-returnvalveNotOK	103	119
		RuptureHoseEmergencystopNotOK Non-returnvalveOK	71	98
		RuptureHoseEmergencystopNotOK Non-returnvalveNotOK	103	142
		LeakageHose	9	3
Methanol	Tank truck	Instantaneous	35	30
		ContinuousLargestConnection	45	41
		BreakagePumpEmergencystopOK	22	20
		BreakagePumpEmergencystopNot OK	30	28
		LeakagePump	7	6
		RuptureHoseEmergencystopOK	25	23
		RuptureHoseEmergencystopNotOK	35	32

Substance	Component	Scenario	1% Death	
			D-5.0 [m]	F1.5 [m]
Substance	Component	Scenario	1% Death	
			D-5.0 [m]	F1.5 [m]
Methanol	Tank truck	LeakageHose	7	6
		Pool fire during transshipment	29	26
Hydrogen gas phase	Gas cylinder battery trailer	Instantaneous	9	9
		Continuous largest connection	34	34
		Hose rupture	34	34
		Hose leakage	4	4
		Fireball fire during transshipment	9	9
Hydrogen liquid	Tank truck	Instantaneous	187	104
		Continuous largest connection	27	26
		Hose rupture	27	26
		Hose leakage	3	3
		BLEVE during transshipment	95	96
Ammonia	Tank truck	Instantaneous	327	449
		Continuous largest connection	494	763
		Pump breakage emergency stop OK	218	282
		Pump breakage emergency stop not OK	346	560
		Pump leakage	78	125
		Rupture unloading hose emergency stop OK	116	153
		Rupture unloading hose emergency stop not OK	193	314
		Leakage unloading hose	0	0

Table 10. Impact distance weather class D-5.0 during the day and F-1.5

References

1	RIVM (National Institute for Public Health and the Environment)	2021	*Handleiding risicoberekeningen BEVI* (Bevi Risk Assessment Manual) (version 4.3 dated 1 January 2021)
2	RIVM	2014	*Interim rekenmethode LNG-bunkerstations* (Provisional calculation method for LNG bunkering stations) Version 1.0 dated 18 December 2014
3	RIVM	2015	*Rekenmethodiek LNG-Tankstations* (Calculation method LNG filling stations) Version 1.0.1 dated 2 February 2015
4	RIVM	2016	*Risico- en effectafstanden waterstoftankstations* (Risk and impact distances hydrogen filling stations) Memo reference 20160149 VLH HAS/Sta/sij dated 3 October 2016
5	Royal HaskoningDHV	2022	*Risicoberekening stilliggend ontgassen* (Risk calculation degassing while stationary) Reference: BI1453-RHD-ZZ-XX-RP-Z-0001 September 2022

Annex 1 Location-related risk results

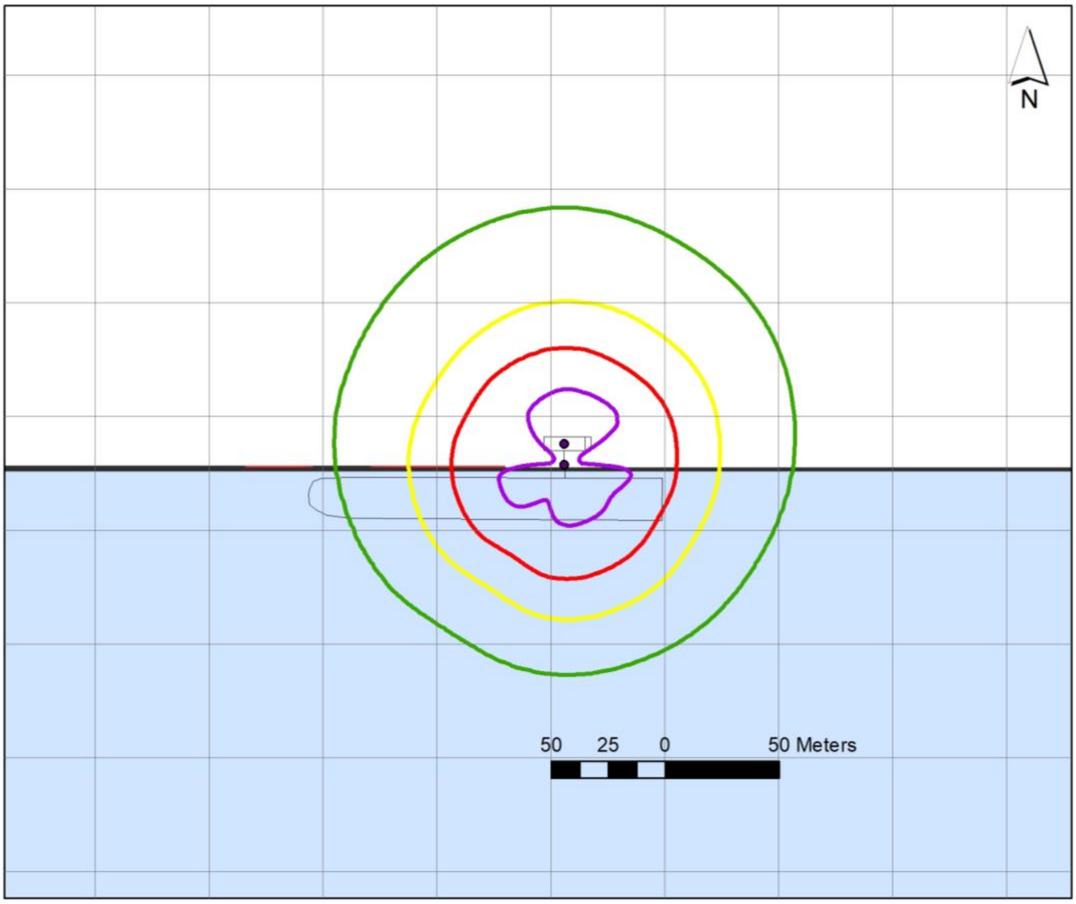


Figure 9. Location-related risk contours (1) stand-alone LNG (single tank truck)

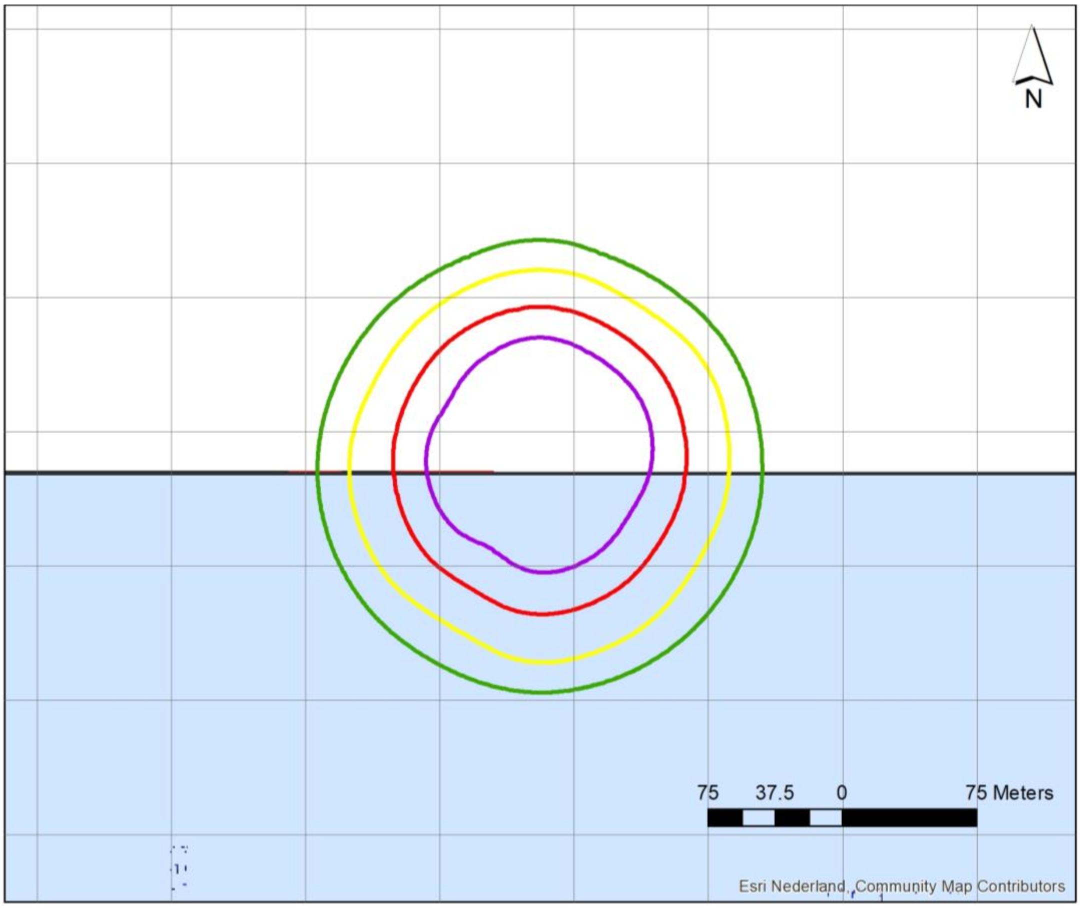
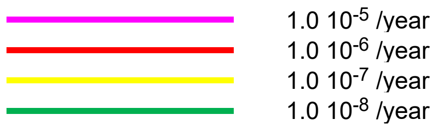


Figure 10. Location-related risk contours (2) stand-alone LNG (T piece 2 tank trucks)



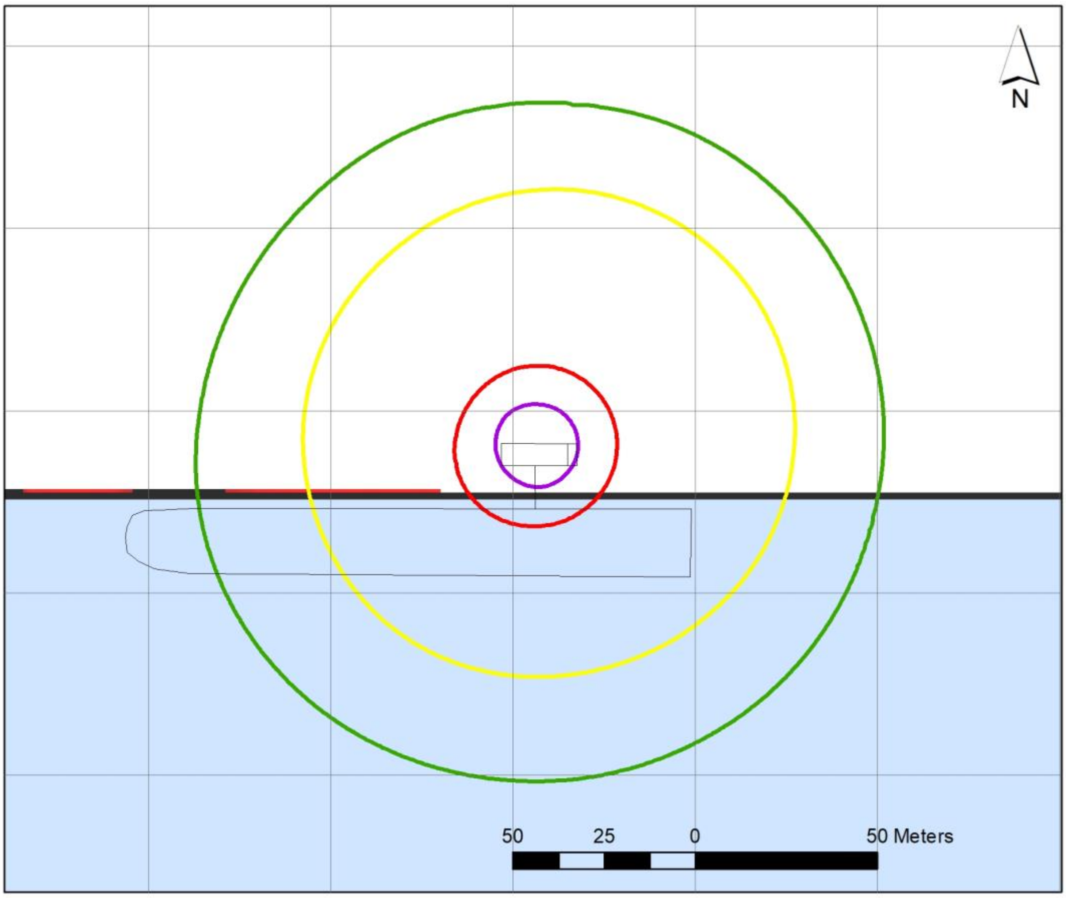


Figure 11. Location-related risk contours (3) stand-alone methanol

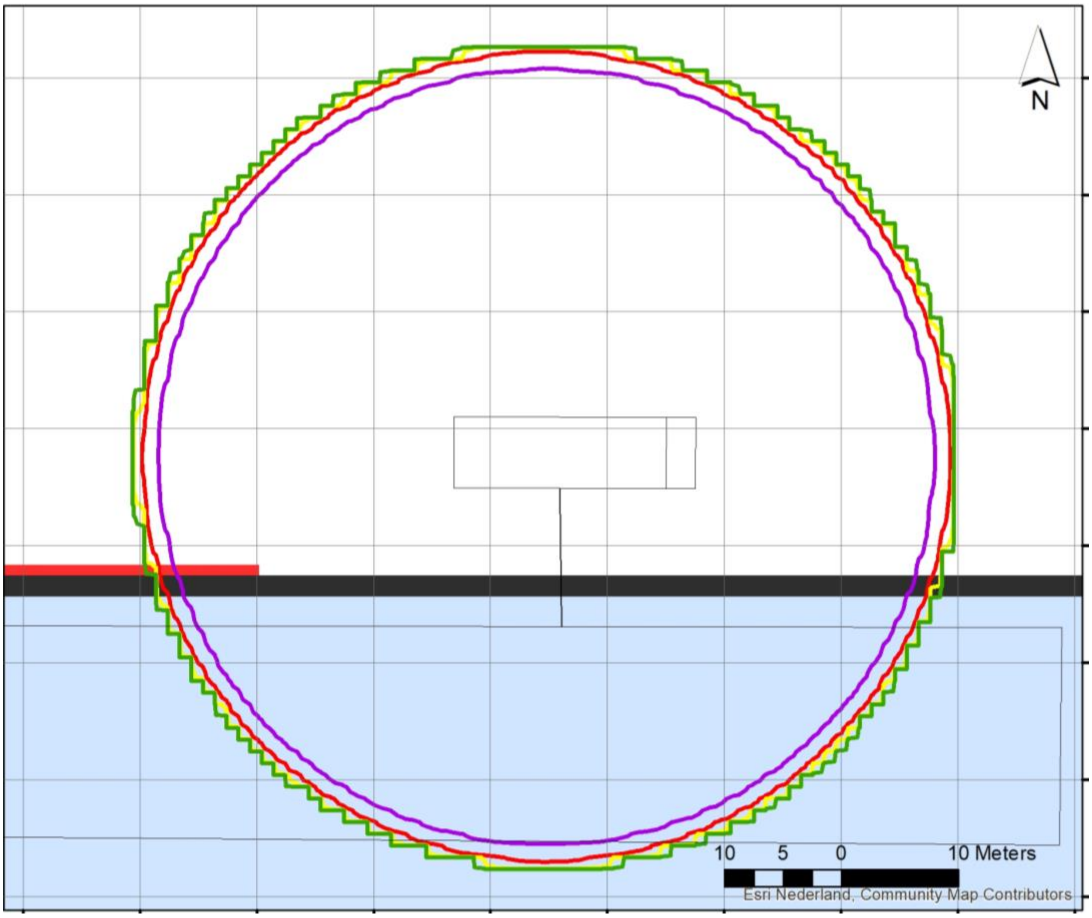


Figure 12. Location-related risk contours (4) stand-alone hydrogen gas

magenta	1.0 10^{-5} /year
red	1.0 10^{-6} /year
yellow	1.0 10^{-7} /year
green	1.0 10^{-8} /year

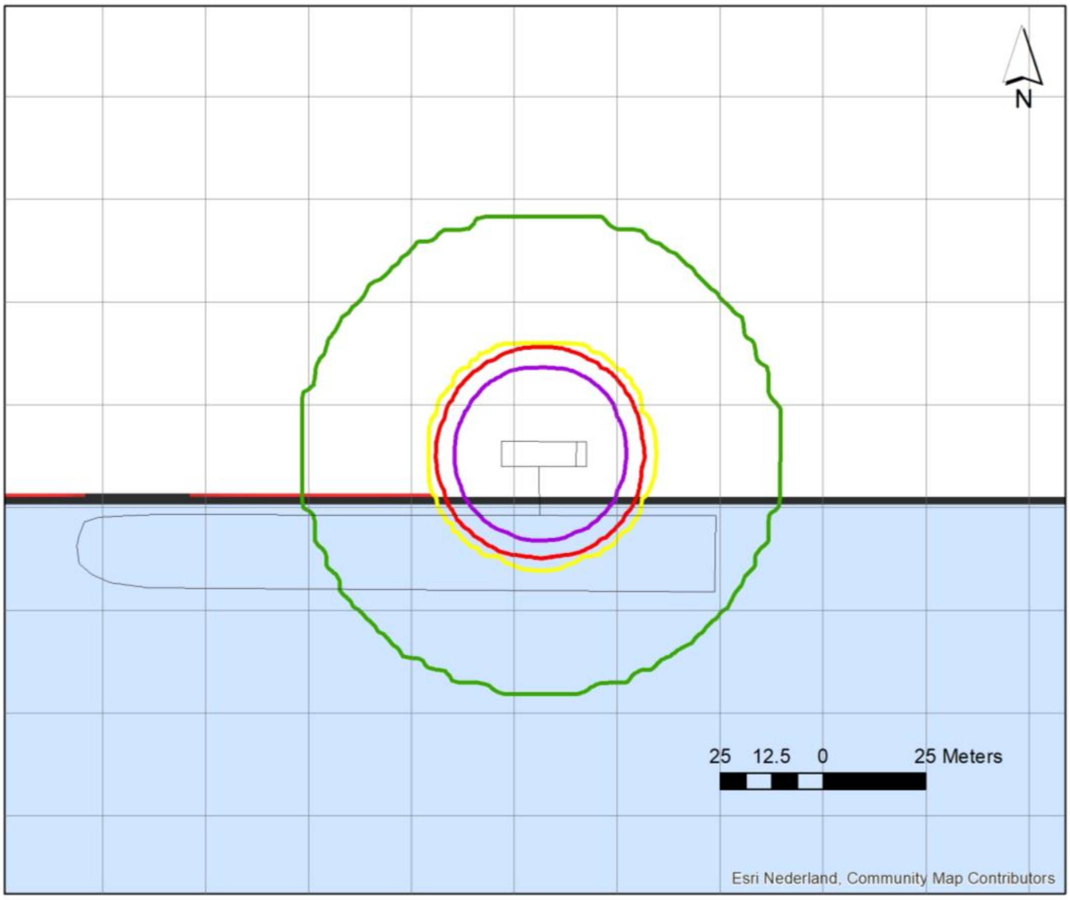


Figure 13. Location-related risk contours (5) stand-alone hydrogen liquid

magenta line	1.0 10^{-5} /year
red line	1.0 10^{-6} /year
yellow line	1.0 10^{-7} /year
green line	1.0 10^{-8} /year

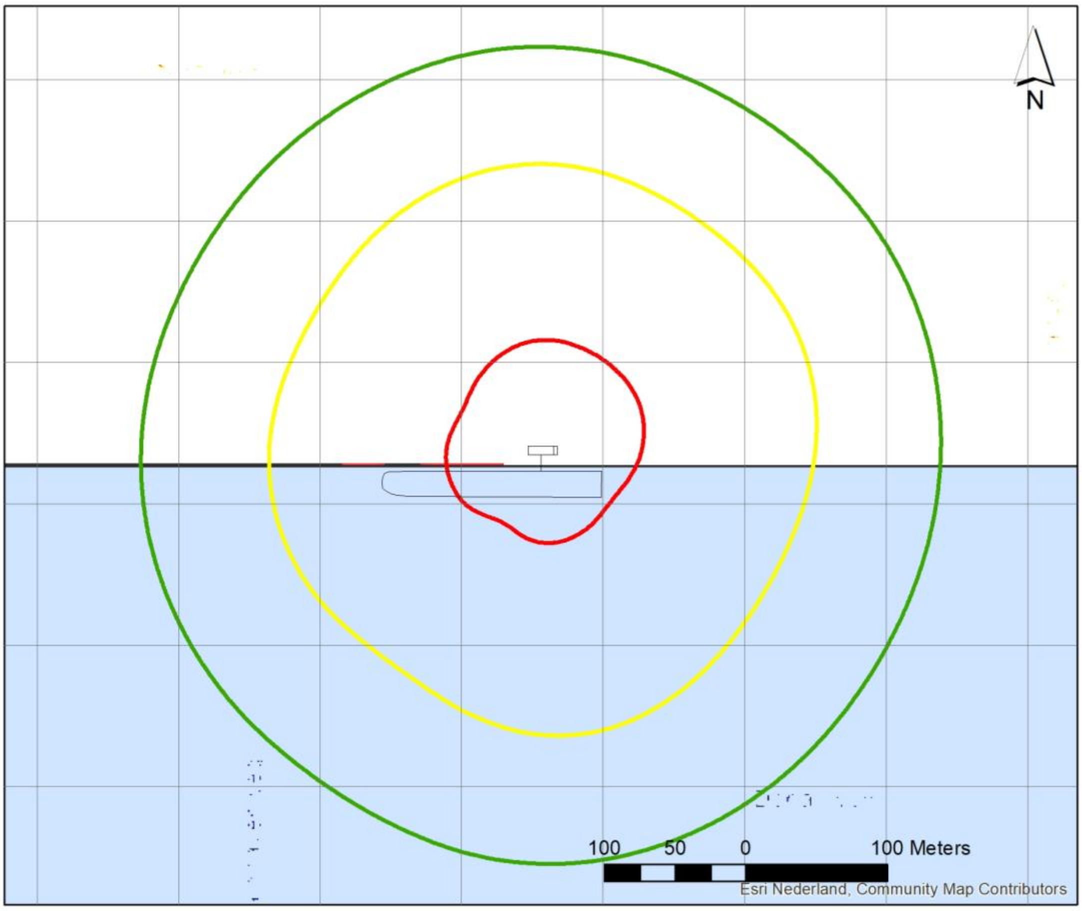
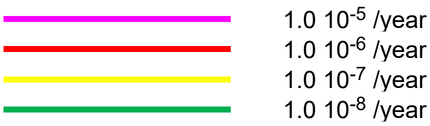


Figure 14. Location-related risk contours (6) stand-alone ammonia



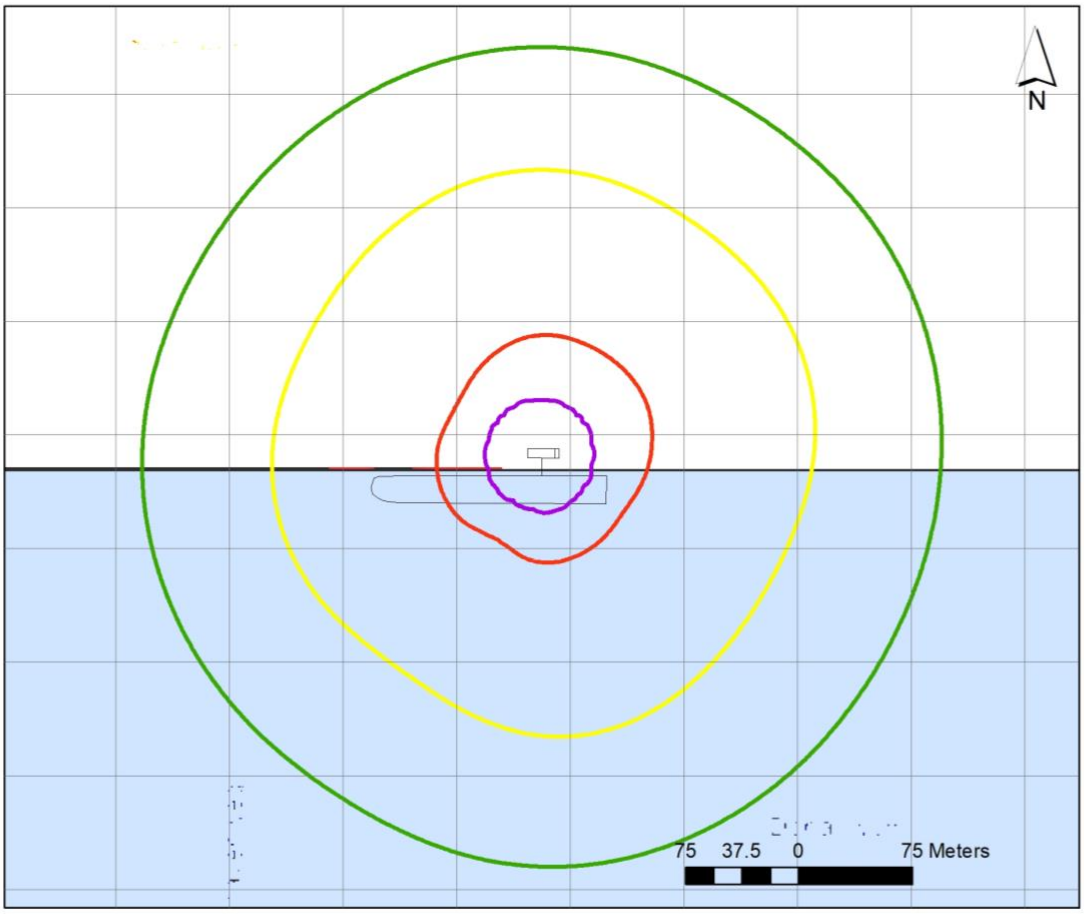
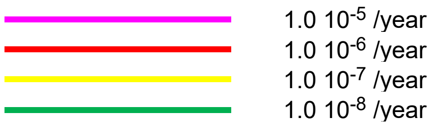


Figure 15. Location-related risk contours (7) all combined with LNG as single tank truck



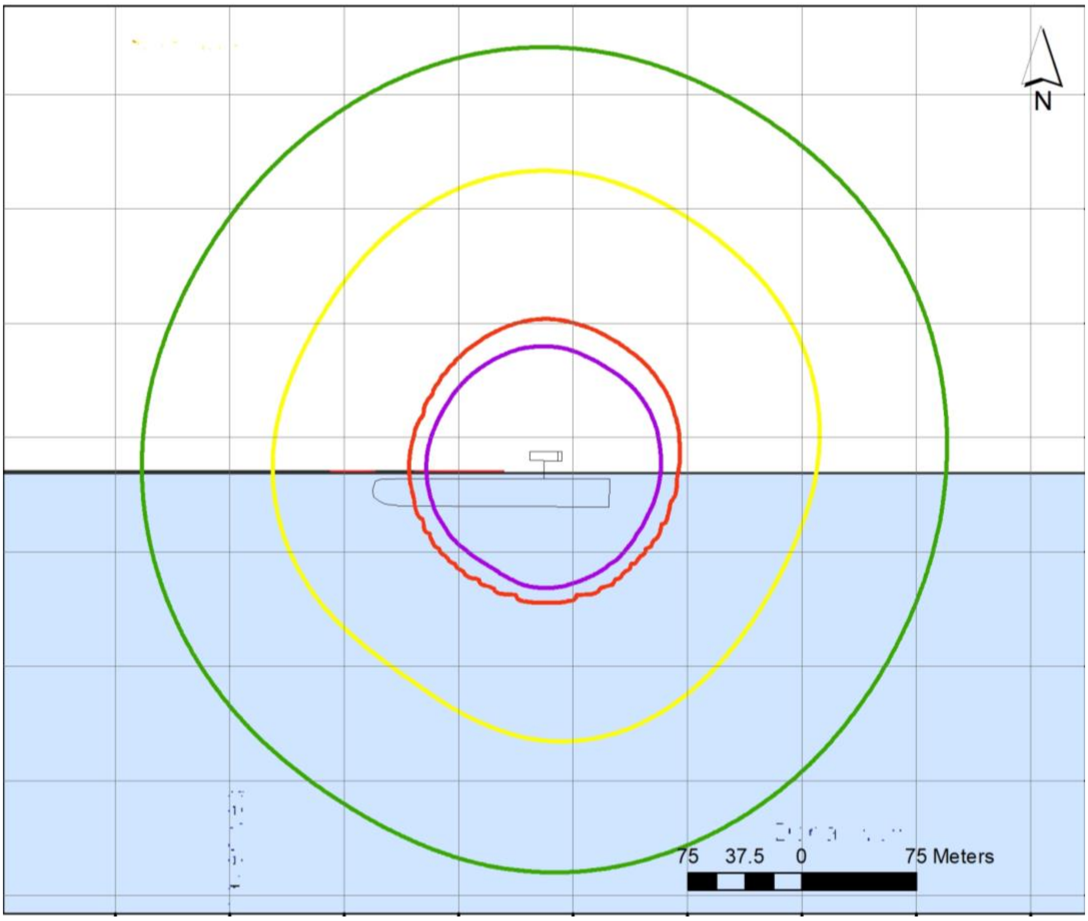
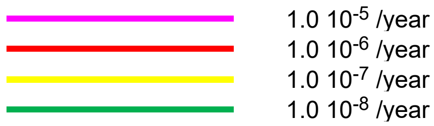


Figure 16. Location-related risk contours (8) all combined with LNG T piece 2 tank trucks



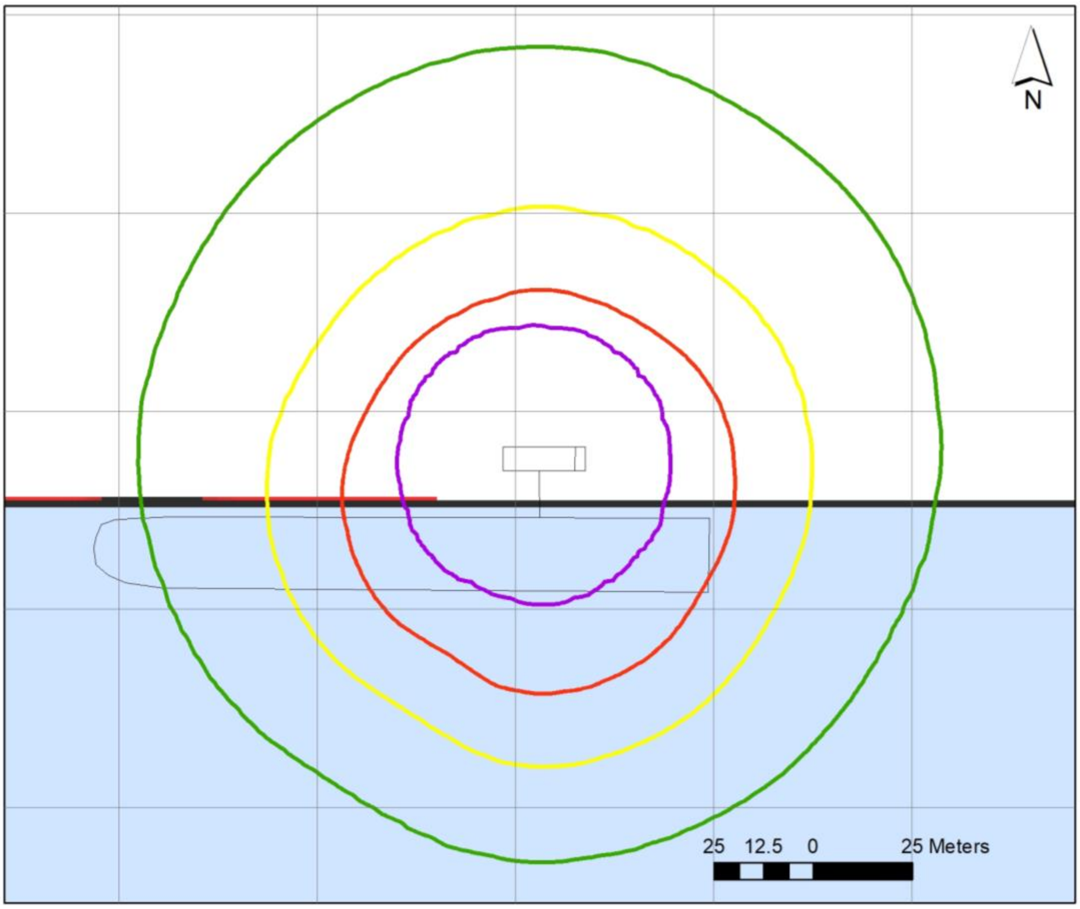


Figure 17. Location-related risk contours (9) all combined without NH3 with LNG as single tank truck

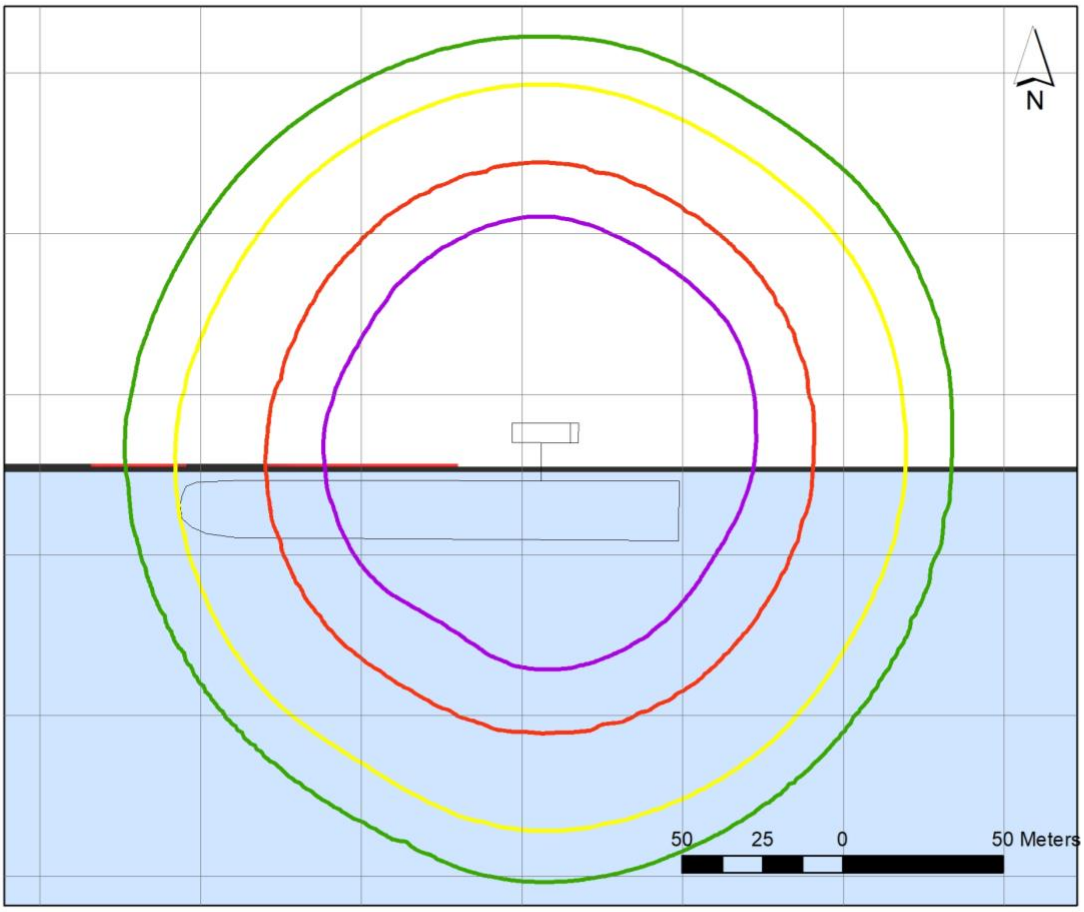
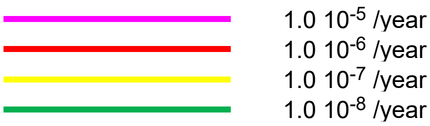


Figure 18. Location-related risk contours (10) all combined without NH3 with LNG T piece 2 tank trucks



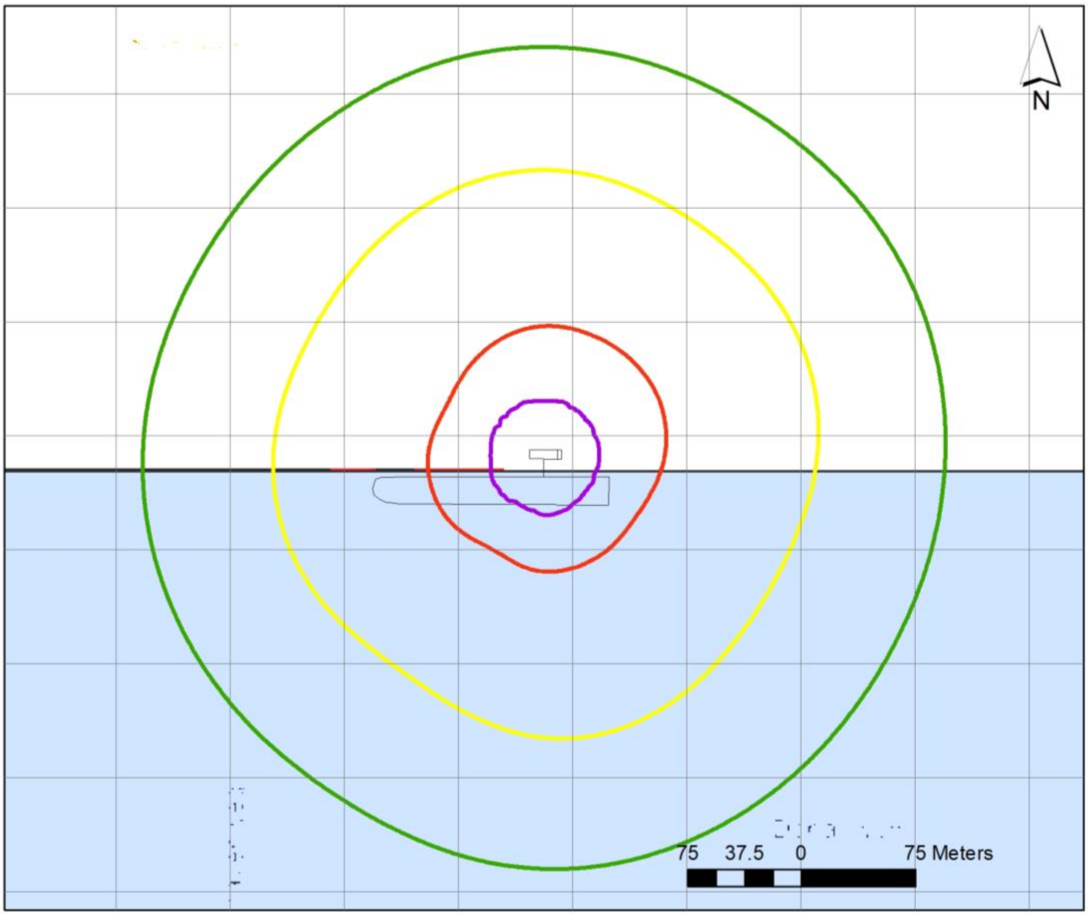


Figure 19. Location-related risk contours (11) all combined with LNG as single tank truck and degassing

(magenta line)	1.0 10^{-5} /year
(red line)	1.0 10^{-6} /year
(yellow line)	1.0 10^{-7} /year
(green line)	1.0 10^{-8} /year

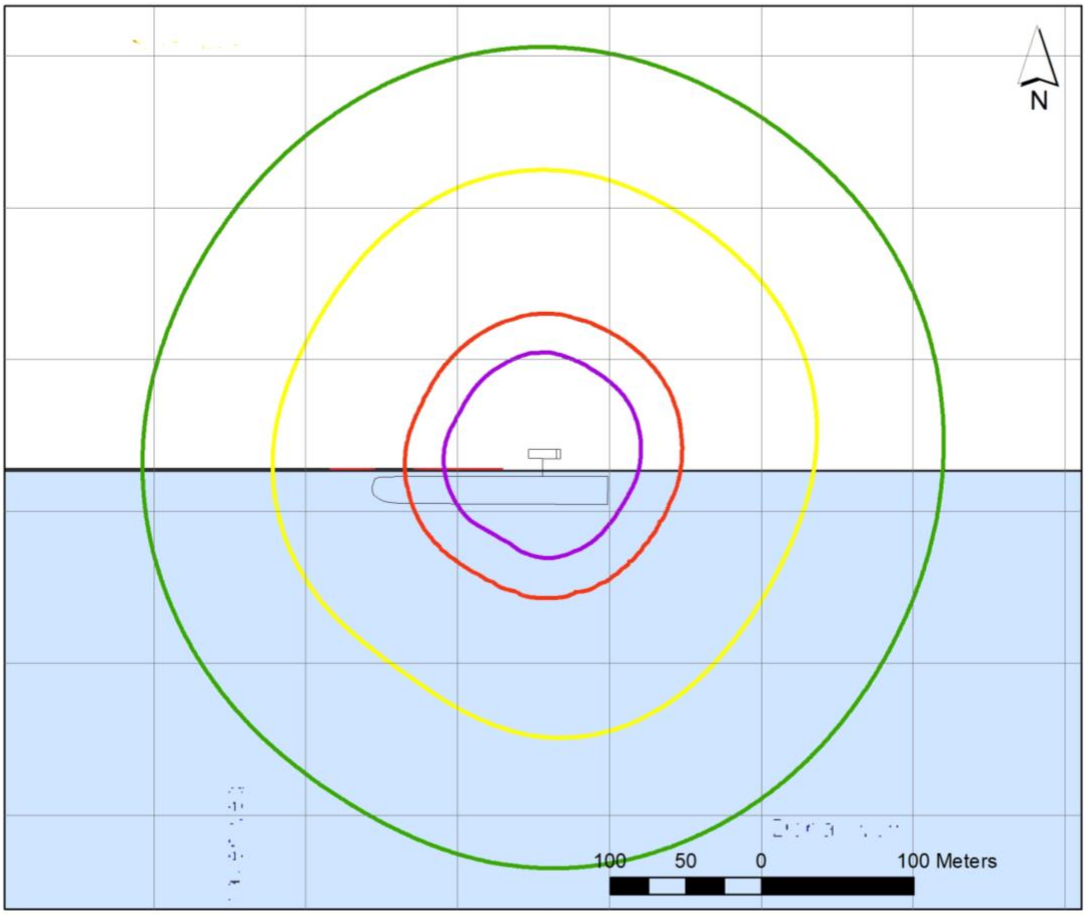
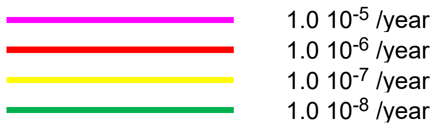


Figure 20. Location-related risk contours (12) all combined with LNG T piece 2 tank trucks and degassing



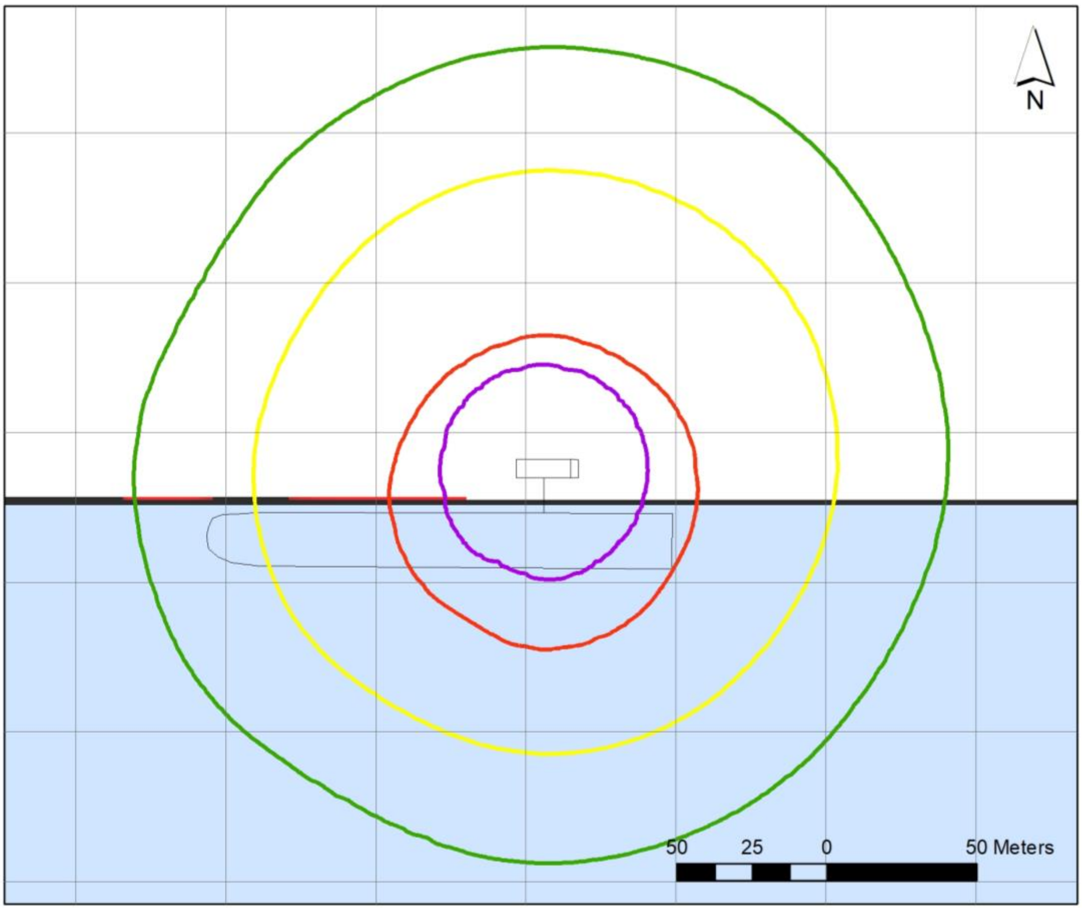


Figure 21. Location-related risk contours (13) all combined without NH3 with LNG as single tank truck and degassing

$1.0\ 10^{-5}$ /year
$1.0\ 10^{-6}$ /year
$1.0\ 10^{-7}$ /year
$1.0\ 10^{-8}$ /year

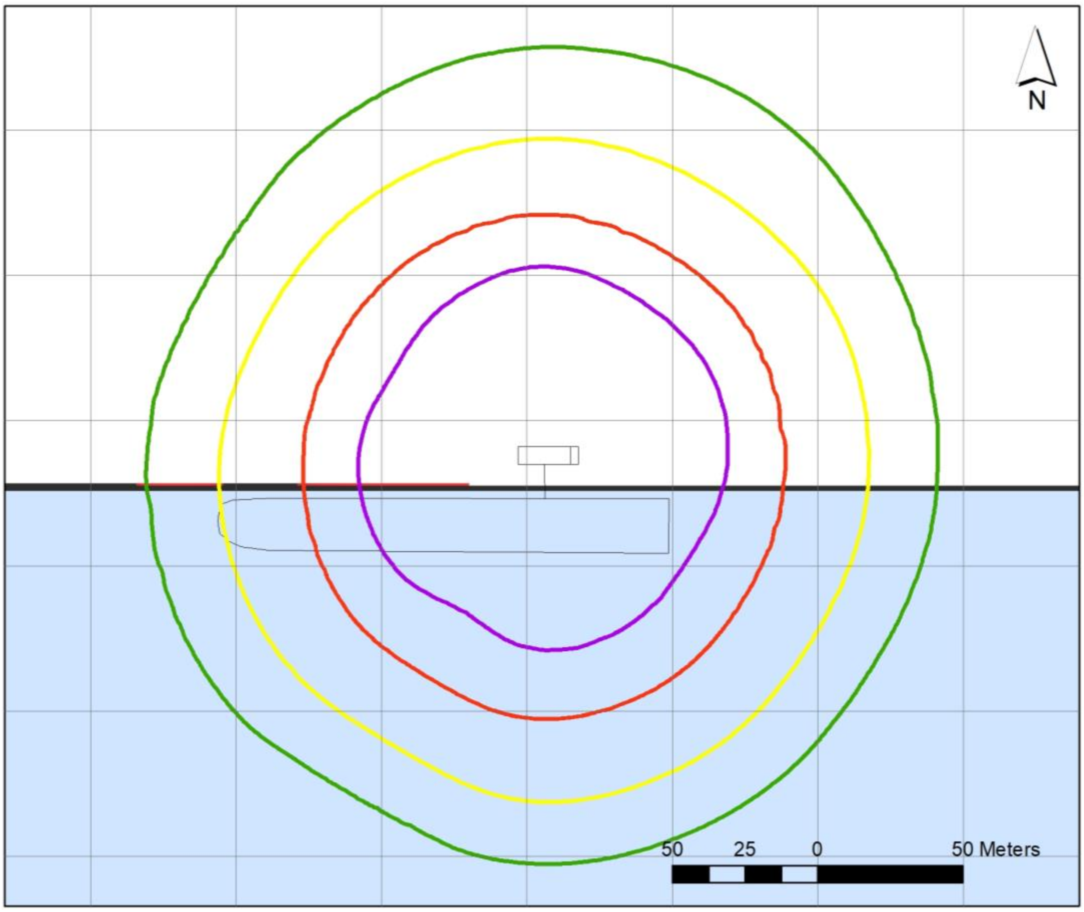


Figure 22. Location-related risk contours (14) all combined without NH3 with LNG T piece 2 tank trucks and degassing

$1.0\ 10^{-5}$ /year
$1.0\ 10^{-6}$ /year
$1.0\ 10^{-7}$ /year
$1.0\ 10^{-8}$ /year