 

# QRA method for land-use planning around natural gas production, processing and transportation sites in the Netherlands

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A Quantitative Risk Assessment (QRA) method has been developed for on-shore natural gas production, processing and transportation sites in the Netherlands. The focus of the QRA method is the risk imposed on the surroundings of the site (third-party risk). The outcomes of the QRA are used for permitting and land-use planning.

Natural gas processing and transportation sites often have a complex layout, with parallel sections of multiple vessels and pipes that are interconnected at the upstream and downstream ends. Sections rapidly depressurize in case of a large leak. The specific site layout with feed of material from storage vessels and high-pressure pipelines is relevant for the resulting (time-dependent) release rate. Therefore, the new QRA method for natural gas production and processing sites provides guidance for the calculation of time-depending release rates in complex systems. In the standard approach, the site layout is simplified considerably and the release is dominated by the flow from the transportation pipelines entering and leaving the natural gas site. The release rate calculation takes into account the presence of active and passive blocking systems. Each release is divided into two (time) stages: one stage that characterizes the start of the release, where release rates can be very high, and another stage that characterizes the release after the initial discharge. For both stages, a jet fire is associated with the release.

The method was tested for twenty-four Dutch establishments. Subsequently, a final version of the method was delivered (RIVM, 2014b). It is expected that the responsible public authority will prescribe the method in 2015 for 300 establishments in the Netherlands.

Keywords: QRA, third-party risk, natural gas, land-use planning, consequence modelling

## Introduction

### Legal framework

In the Netherlands, establishments where flammable and/or toxic substances are stored and/or processed must carry out a quantitative risk assessment (QRA) to determine the risk that they impose on the surroundings. The outcomes of these risk assessments are used for permitting and land-use planning. According to the (Dutch) Decree External Safety around Establishments (Bevi), no ‘vulnerable objects’, such as houses, schools and large office buildings, are allowed in the area where the probability of fatality exceeds $10^{-6}$ (one in a million) per year. Therefore, no permits should be granted if such vulnerable objects are present within this area and no new vulnerable objects should be built within this area if an establishment already has a permit.

In order to obtain consistent results, the method to carry out QRAs is prescribed (RIVM, 2009). The method defines which release scenarios and release frequencies must be considered and how the consequences and possible impact on people must be calculated. The current method includes establishments that fall under the scope of the EU Seveso directive, as well as other types of establishments such as LPG filling stations and chemical warehouses. The method must contain a high level of detail, because otherwise, outcomes are subject to personal interpretations that can be easily challenged in court. Further information on the Dutch legislative context including recent experiences can be found in (Uijt de Haag, 2013).

### On-shore natural gas production, processing and transportation sites

Around 300 on-shore establishments where natural gas is produced, injected, cleaned and/or transported, currently exist in the Netherlands. With a few exceptions, these sites are not yet included in the Decree External Safety around Establishments (Bevi). However, as they impose a risk on the surroundings, inclusion in the legislation is desired. As a result, the existing QRA method must be expanded in order to include the following activities.

*On-shore natural gas production*

This activity involves the production of natural gas and limited amounts of natural gas condensate from on-shore production wells. Off-shore natural gas production is not considered because it is not relevant for land-use planning. Drillings for gas and oil are not part of the QRA method as these activities are single occurrences and therefore not included in the Decree External Safety around Establishments (Bevi). However, parts of the method can be used to address the risks associated with drilling.

*On-shore natural gas injection*

This activity involves the injection of natural gas into existing, partly empty, natural gas reservoirs, for underground gas storage.

*Natural gas processing*

This activity involves the removal of natural gas condensate and solid particles using various types of separators and heat exchangers.

*Natural gas transportation*

This activity includes sites for compression of gas for further transportation in the national grid, sites for pressure reduction for transfer to local grids and sites for measurement of flow rate and caloric value of natural gas streams prior to export.

Figure 1 shows where the natural gas production and processing sites are located. GIS coordinates for transportation sites were not available.

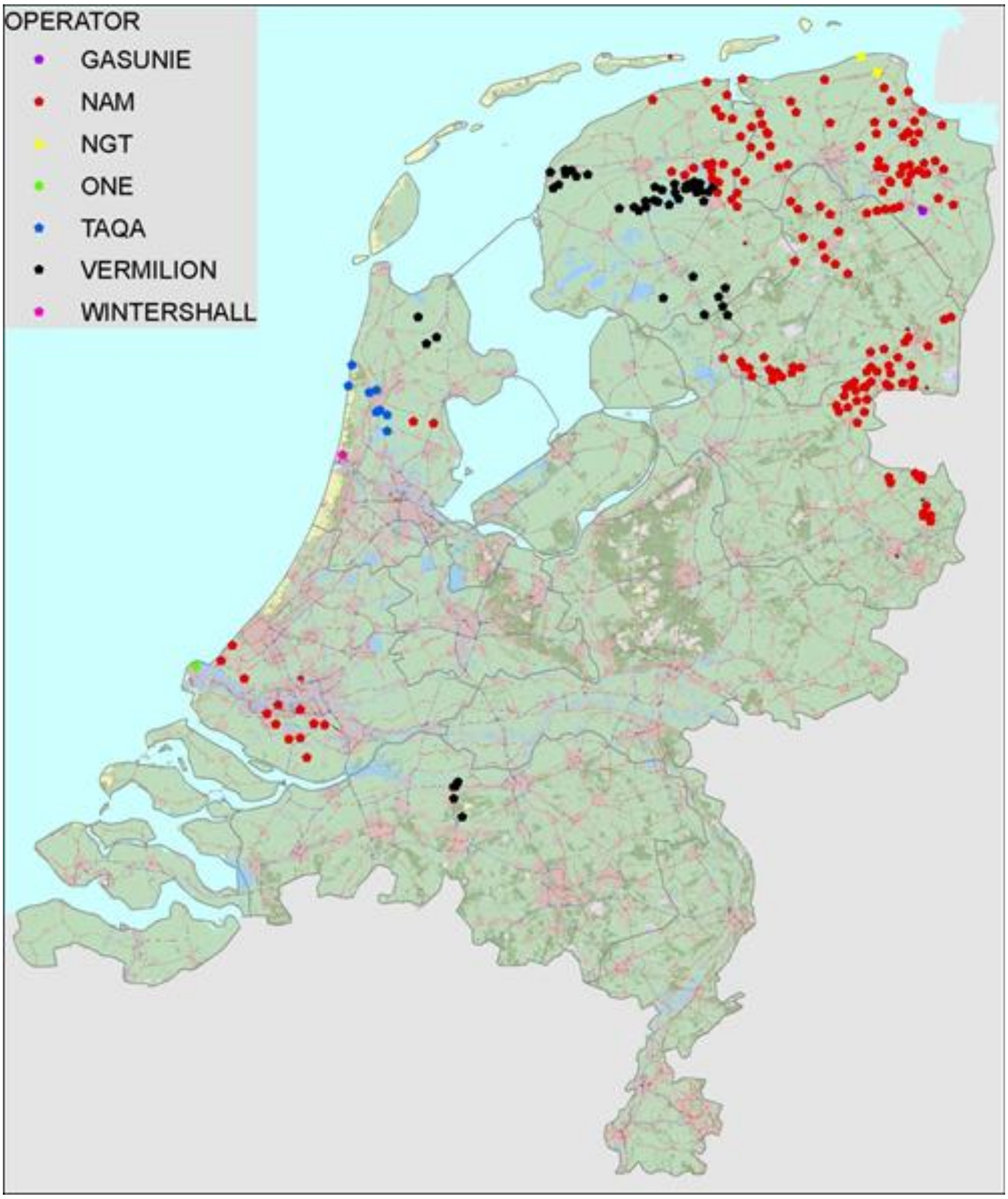


**Figure 1 Location of natural gas production and processing sites (transportation sites not displayed)**

## Research question and requirements

The research question was to draft a prescribed QRA method for on-shore natural gas facilities. In order to define the QRA method, the following questions had to be addressed:

- Which release scenarios should be considered and what are the associated release frequencies?
- What is the release rate as a function of time, taking into account the layout (or design) of the establishment, including isolation valves?
- What is the ignition probability of a release, as a function of release rate, release direction, time and presence of ignition sources?
- Which types of consequences should be considered?

Though all these questions have been addressed in public literature, few methods exist that combine these elements in a coherent framework. Moreover, a specific approach for natural gas facilities was lacking. The construction of a coherent QRA framework for the calculation of third party risk around natural gas facilities is therefore the topic of the study.

A number of general requirements were defined at the start of the project. These are:

- The method must be clear and precise and not leave room for personal interpretation.
- The method must be coherent with the QRA method that is already in place for Seveso establishments for issues that are not specific for production, injection, processing and transportation of natural gas. The method can only deviate from the existing method for issues that are specific for natural gas facilities.
- In order to be transparent to the general public, only publically available information can be used.
- The method must lead to realistic outcomes when reliable information is available and to conservative outcomes when information is missing.
- The method should use SAFETI-NL™ as this is the selected tool for risk assessment in the Netherlands (including consequence and impact assessment).

### Outline of the paper

In this paper, the new QRA method for on-shore natural gas production, processing and transportation sites is presented. First, an overview of the new QRA method will be provided. Subsequently, the underlying arguments behind the decisions made, will be presented. The method will then be illustrated with a simple example. At the end of the paper, outcomes for the application of the method to real cases will be summarised.

## Overview of the new QRA method

The main task was to develop a QRA method that is reliable and sufficiently detailed to obtain identical results for identical cases. Therefore, the method needed to define the release scenarios and release frequencies to be accounted for, the calculation method for the release rate, the ignition probabilities for the identified releases, and the consequence events to be used for impact calculation. The method was published in November 2014 (RIVM, 2014b). A version in Dutch can be downloaded from the website. This paper presents an overview of the new method.

### Scenarios and release frequencies

The standard QRA method (RIVM, 2009) defines which release scenarios and frequencies must be included in the QRA for Dutch Seveso sites. Table 1 shows the types of equipment used within natural gas facilities and the release scenarios that should be included in the QRA. For production and injection wells, new scenarios and frequencies were derived. For pipelines and compressors, new release frequencies were derived that are specific for high-pressure equipment. More details about the study of release scenarios and frequencies can be found in (Kooi, 2013).

**Table 1 Typical equipment and scenarios to be used in the QRA**

| Type of equipment | Subtype | Scenarios to be considered |
|---|---|---|
| Production and injection wells | Production, injection, wireline, coiled tubing, snubbing, workover. | Blowout from a well<br>Leak from a well |
| Pipelines | High-pressure pipelines, flexible pipelines | Rupture of a pipeline<br>Leak from a pipeline |
| Separators | Knockout vessels, slug catchers, absorbers, centrifugal separators, filter separators | Catastrophic rupture<br>Leak from the separator |
| Pumps/compressors | High-pressure natural gas compressors | Rupture of associated pipes<br>Leak from associated pipes |
| Heat exchangers | Fin fan coolers, various vessel type heat exchangers | Catastrophic rupture<br>Leak from the heat exchanger |

### Release rate

The sites considered may consist of parallel sections (or trains) of equipment that are interconnected at the upstream and downstream ends. An example of a small production site with gas/liquid separation is shown in Figure 2. In order to calculate the release rate, the depressurisation of the installation must be considered while at the same time, inflow from connected parts of the installation should be accounted for. More complex sites may have more incoming and/or outgoing streams, more sections (e.g. additional adsorption, filtering, monitoring, compression) and more than two parallel trains per section.

For rupture of aboveground pipelines and vessels, the releases from the upstream and downstream sides of the failing equipment are treated separately, yielding to two independent jets with horizontal release direction. For underground equipment, the contributions from the upstream and downstream directions are combined and released vertically. Leaks always result in a single jet.

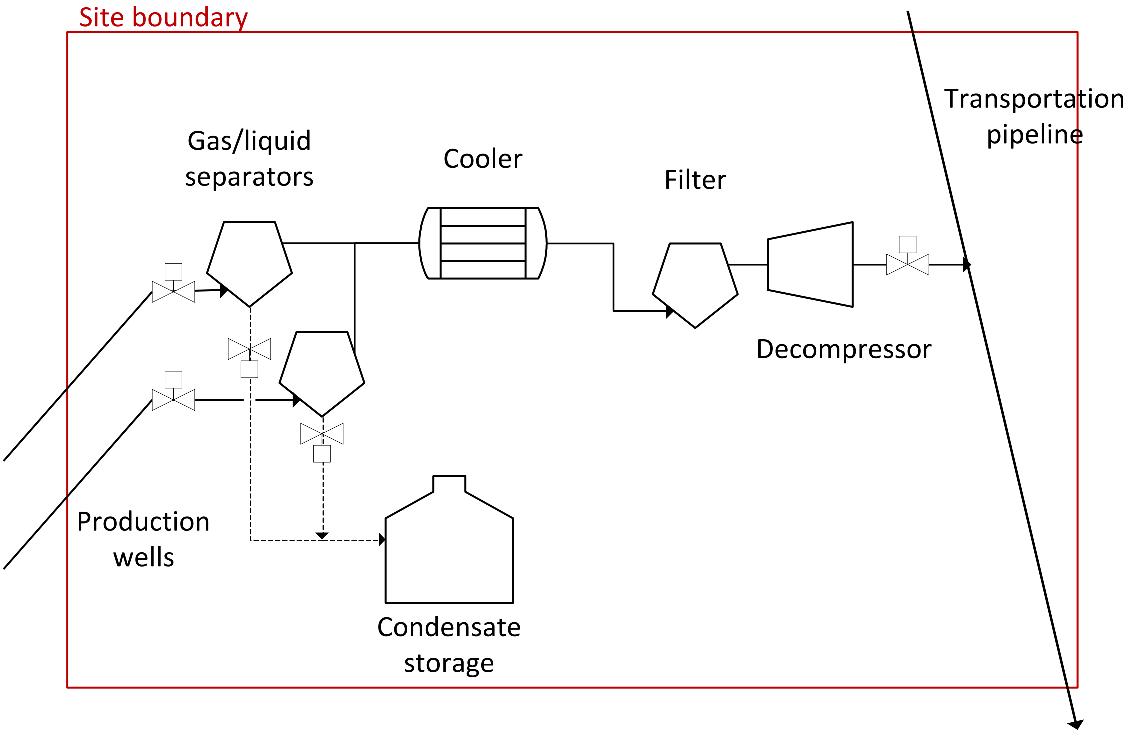


**Figure 2** **Example of a small production site. The solid lines represent high-pressure natural gas pipelines, while the dotted lines represent condensate pipes.**

Each release is divided into two (time) stages: one stage that typifies the start of the release, when release rates can be very high, and another stage that typifies the release after the initial discharge. For the first stage, the average release rate during the first 20 s is used, and for the second stage, the average rate in the next two minutes (i.e. between 20 and 140 s). For emergency shut-down (ESD) systems, it is assumed that they start to respond after the release has started, i.e. not prior to the release. Typically, closing of the valves will require 10 to 40 s, depending on the response time of the system and the closing time of the valves. To simplify the calculations, the impact of ESD systems is entirely ignored for the first release stage (0 to 20 s). An exception is made for fast closing valves with a closing time below 5 s. For installations with fast closing valves, a tailor-made release rate calculation is allowed. For the second stage, the impact of ESD systems can be accounted for and the impact can be substantial.

The standard approach for installations without fast closing valves is summarised in Table 2.

**Table 2** **Release scenarios for installations without fast closing valves (wells excluded)**

| **Type of equipment** | **Release scenario** | **Subscenarios for QRA** |
|---|---|---|
| Aboveground vessel or pipe | Rupture | Horizontal release with feed from upstream direction – early stage<br>Horizontal release with feed from upstream direction – late stage<br>Horizontal release with feed from downstream direction – early stage<br>Horizontal release with feed from downstream direction – late stage |
| | Leak | Horizontal release (fixed flow rate) |
| Underground vessel or pipe | Rupture | Vertical release with feed from both directions – early stage<br>Vertical release with feed from both directions – late stage |
| | Leak | Vertical release (fixed flow rate) |
| Well (production/injection) | Blowout | Vertical release with feed from site – early stage<br>Vertical release with feed from site – late stage |
| | Leak | Vertical release (fixed flow rate)<br>Horizontal release (fixed flow rate) |
| Well (maintenance activity) | Blowout | Vertical release – early stage<br>Vertical release – late stage |
| | Leak | Vertical release (fixed flow rate)<br>Horizontal release (fixed flow rate) |

For rupture scenarios, the release rate model should be capable of taking into account both time-dependence of the outflow and feed from adjacent systems. Between the various available models in SAFETI-NL™, it was decided that the Long Pipeline model was best suited. A simplified approach was invented, consisting of the following two assumptions: (1) the orifice size for the release scenario is equal to the diameter of the pipe (or pipe connection) considered, and (2) the diameter of the Long Pipeline is equal to the diameter of the feed line to the facility. It was verified that this approach will generally produce outcomes that are mildly conservative. An advantage of the simplification is that it is relatively easy to carry out, thereby reducing the likelihood of input errors. Another advantage is that it leaves little room for interpretation, thereby reducing differences in outcomes for similar situations. The most important advantage however, is that it is no longer necessary to take into account the full details of the layout of the site.

### Associated consequence events

Almost all releases, including catastrophic ruptures of vessels, lead to a prolonged release with backflow (feed) from connected parts of the establishment. Ignition of a release is therefore expected to give a jet fire. Deviations from the jet fire approach are only allowed for installations with fast closing valves and for installations that are isolated during parts of the year (for example absorbers that are isolated during the injection season).

### Ignition probabilities

Ignition probabilities need to be defined for both the first and second stage of the release. The ignition probabilities add up to one and are listed in Table 3. It should be noted that the current paper is dedicated to natural gas sites; different ignition probabilities apply to releases of condensate and oil.

**Table 3 Ignition probabilities for (on-site) natural gas horizontal releases**

| Release rate | Probability of early ignition (between 0-20 s) | Probability of late ignition (between 20-140 s)* |
|---|---|---|
| Less than 10 kg/s | 0.02 | 0.98 |
| Between 10 and 100 kg/s | 0.05 | 0.95 |
| Larger than 100 kg/s | 0.09 | 0.91 |

* Only in case the flammable cloud extends beyond the site boundary (mainly horizontal releases); otherwise the probability of late ignition is zero (mainly vertical releases)

## Justification of the new method

### Scenarios and release frequencies

The derivation of scenarios and release frequencies has been described in other papers and will not be repeated here. General information on the methodology and the assumptions used can be found in (Kooi, 2011) and (Kooi, 2013). The derivation of the release scenarios and frequencies for onsite high-pressure natural gas piping has been reported in (Van Vliet, 2011).

In general, the derivation of frequencies for (catastrophic) ruptures was difficult. For example, no major pipeline ruptures have occurred within Dutch onshore natural gas establishments since the beginning of the registration of data. However, as the number of experience years is limited, frequencies in the order of $10^{-8}$ per meter or lower could not be ruled out. In this particular case, underground transportation pipelines were used as an analogy (Laheij, 2012, Van Vliet, 2011).

There was a debate whether the rupture frequencies for high-pressure pipelines could be modified depending on e.g. wall thickness or the presence of fire and gas detection systems. The contribution of domino-events, either due to impact with vehicles or with falling objects, or due to fire impingement from a nearby leak, is not included in the base frequency and should therefore be assessed separately. A procedure for this analysis was defined. Relating to wall thickness, the amount of available data was too limited to determine the influence of pipe wall thickness on failure causes such as corrosion and mechanical failure. The resulting failure frequencies are therefore independent of wall thickness and increasing the wall thickness will not yield to a reduction of calculated risk.

### Release rate calculation

Natural gas sites have two features that make consequence assessment complicated. The first is that the sections with compressed natural gas will rapidly depressurise when a major leak occurs. As a result, the release rate will decrease very rapidly in time. Secondly, natural gas sites typically consists of parallel sections (or trains) of equipment that are interconnected at the upstream and downstream ends. When a large leak occurs, gas will not only be released from the equipment type that fails but there is also inflow of gas towards the leak from connected parts of the establishment. Tools that are commonly used for risk assessment are not well-suited to predict the resulting flow. This is illustrated with the following example.

Suppose that a pipe rupture occurs before the cooler (see Figure 3). This will result in an upstream flow from the two wells and the gas/liquid separators in-between. In addition, a downstream flow will start that is fed by the gas in the downstream part of the site and the transportation pipeline.

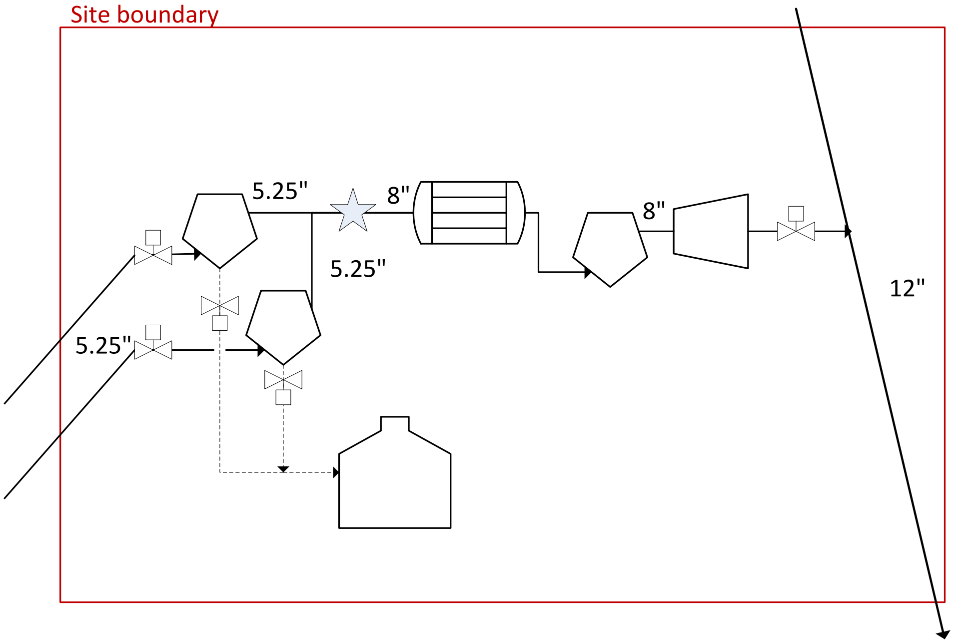


**Figure 3 Example with fictional rupture location and pipeline diameters**

Typically, the following types of models are available to analyse both streams:

- Simple leak models; these models calculate a constant release rate depending on the initial pressure and the orifice diameter. These models overestimate the release rate as depressurisation of the system is not accounted for.
- Time-varying (TV) release models; these models calculate the release rate from a (pipe connected to a) fixed depressurising volume. These models underestimate the release rate if the chosen volume is too small and overestimate the release rate if the volume is too large. The right size of the reservoir is difficult to define, because the system of interconnected vessels and pipes behaves different from a release from a single reservoir.
- Time-varying long pipeline models; these models calculate the release rate for a depressurising long pipeline (with or without pumped inflow). For these scenarios, the release rate depends mostly on the pressure and the diameter defined for the pipeline. The main challenge is to define the right diameter.

The behaviour of these models is illustrated for the downstream flow in Figure 4, using the following site characteristics:

- Production wells (each): tubing diameter 5¼", casing diameter 7", reservoir depth 3 km, reservoir temperature 70°C, flowing bottom hole pressure 60 bar(g), tubing blowout potential 10 kg/s.
- Pipes between the production wells and the header: diameter 5¼" (0.13 m) each, length 10 m per section, pressure 60 bar(g).
- Pipes downstream from the header: diameter 8" (0.20 m) each, length 10 m per section, pressure 60 bar(g).
- Knockout (separator) vessels and cooler: volume 15 m3 each, pressure 60 bar(g).
- Transportation pipeline: diameter 12" (0.30 m), pressure 40 bar(g), temperature 10°C, length 20 km. Note: the pipeline itself is not considered as being part of the establishment, but inflow from the pipeline is accounted for.

Though the example is somewhat simplified, it is clear that the differences in the predicted release rates for identical cases can be substantial, up to a factor 10 for complex cases. Therefore, a unified approach is desired.

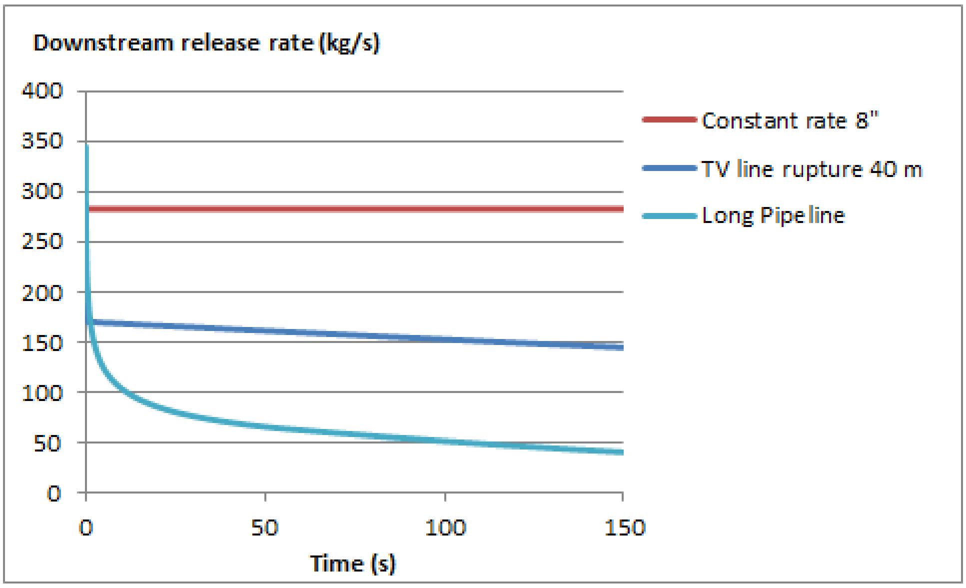


**Figure 4 Calculated release rates from the downstream direction (SAFETI-NL™) for three different models (see text)**

The Long Pipeline model in SAFETI-NL™ was selected as the default model for the calculation of release rate. The main reasoning of the proposed calculation method is that the inflow of the feed lines is defining the release rate after the short, initial outflow of the installations' hold-up. The Long Pipeline model can also account for depressurisation during the release. A simplification was made in which the characteristics of the Long Pipeline are equal to those of the feed lines. The actual pipe that ruptures is only relevant for the orifice size. This is illustrated in Table 4.

**Table 4 Input values for simplified Long Pipeline approach**

| Subscenario | Realistic release | Simplified Long Pipeline approach |
|---|---|---|
| Rupture with feed from upstream direction | Initially: 8" hole in 8" pipe at 60 bar(g). Eventually: two depressurising well tubings diameter 5.25" each (equivalent diameter 7.4"), initial pressure 60 bar(g), orifice size 8". | Long Pipeline with 7.4" diameter, pressure 60 bar(g) and hole size 7.4". |
| Rupture with feed from downstream direction | Initially: 8" hole in 8" pipe at 60 bar(g). Eventually: depressurising transportation pipeline, diameter 12", initial pressure 40 bar(g), orifice size 8". | Long Pipeline with 12" diameter, pressure 40 bar(g) and hole size 8". |

Note: the inputs for the rupture with feed from the downstream direction were used in Figure 4.

For the subscenario with feed from the upstream direction, the simplification could lead to a small underprediction of the release rate at the start of the release, because the real orifice diameter is 8" whereas an orifice diameter of 7.4" is modelled. For later stages, the feed from the production wells is overpredicted, as the feed from the two 5.25" well tubings is simplified with a single 7.4" equivalent diameter pipeline. For the subscenario with feed from the downstream direction, the modelled outcomes are expected to be conservative for both early and later stages of the release. The reason is that the real system (8" hole in an 8" pipe connected to a 12" pipe) will depressurise faster than the modelled system (8" hole in a 12" pipe). The modelled system will only underpredict the (initial) release rate if the volume of the vessels between the rupture location and the 12" feed line is large. In the current example, the volume of the filter is negligible.

The impact of ESD systems is illustrated for a fictional case in Figure 5. The blue line shows the release rate in absence of an ESD system, the dotted black and blue lines show the time-averaged values that are used in the risk calculation. The brown line shows the realistic release rate in case an ESD system responds. A response time of 2 s is assumed. After 2 s, the ESD valves start to close, thereby limiting the flow to the installation and decreasing the release rate. The ESD valves are assumed to be fully closed after 30 s. The purple line shows the calculated release rate in SAFETI-NL™. The model is simplified as it assumes that the closing of the valves occurs instantaneously. In the QRA method, the time for closing of the valves is therefore set to the time that the valves are fully closed. As a result, release rates are slightly higher when compared to the realistic case. Nevertheless, the impact on the inputs for the risk analysis is substantial. As a result, the effectiveness of ESD systems is largely reflected in the outcomes of the risk calculation.

An important assumption is that installations are not isolated by ESD systems (including shut-down systems based on Fire & Gas detection) prior to the start of the release. This possibility was investigated but it was not possible to define which fraction of the release frequency was the result of a domino-effect (see subsection with justification of scenarios and release frequencies). For this part, the method is possibly conservative.

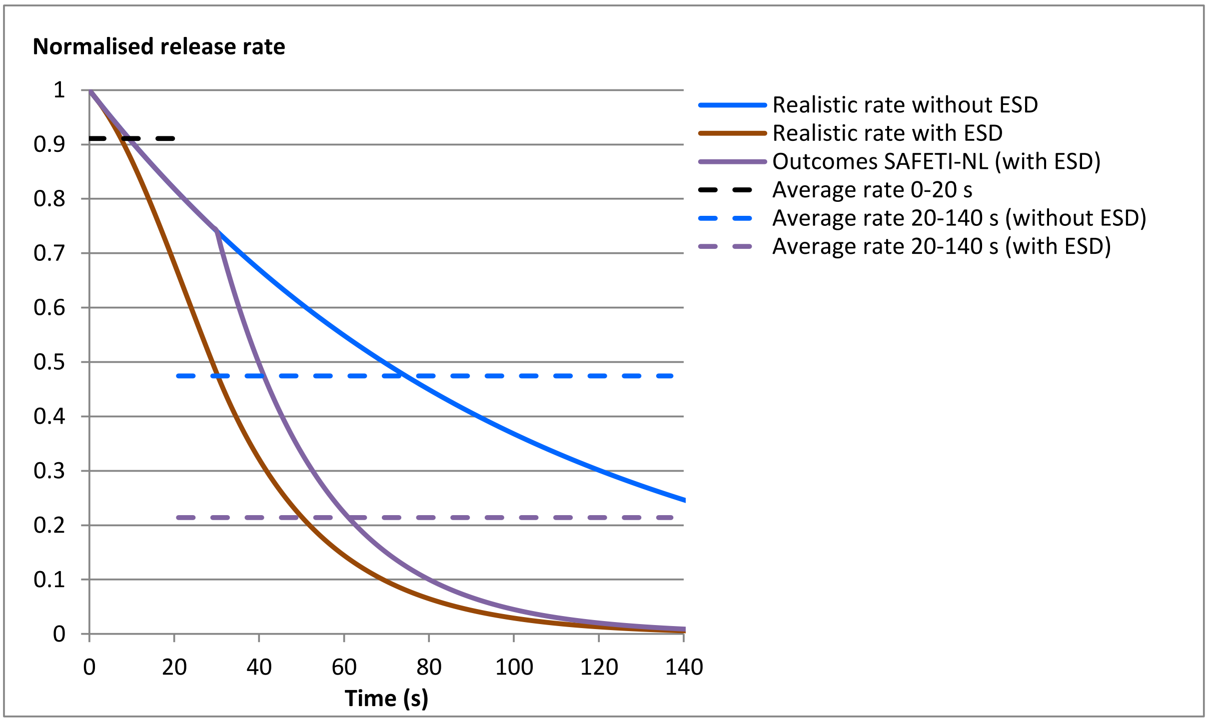


**Figure 5 Simplified example of the effect of ESD systems**

Apart from the models described previously, CFD models can also be used to calculate the release rate. However, CFD models require a difficult selection of boundary conditions and the reliability of the outcomes may be subject to debate. It was expected that it would be very difficult to provide guidance that would lead to standardised results (identical outcomes for identical cases). In addition, CFD calculations are still (too) time-consuming, in particular considering the multitude of scenarios that must be considered in a QRA.

## Associated consequence events

The consequence events considered are jet fires only. The fraction of toxic substances, such as H2S, in the produced gas, is usually below 1% for Dutch natural gas reservoirs. Therefore, toxic effects were not deemed relevant in comparison with flammable effects. Only if streams exist in which the fraction of toxic substances is larger than 4.3%, toxic effects need to be considered.

During the first five to ten seconds of the release, the release rate will decrease very rapidly, as can be observed in Figure 4. If ignition occurs in this period, a transient fire may occur. However, substantial uncertainty pertains to the behaviour of such a fire and to the likelihood that it can ignite. In addition, such transient fire effects cannot be modelled with the selected software yet (SAFETI-NL™).

The release rate will stabilise after the first five to ten seconds. Ignition of this pseudo-stable jet is possible and the associated effect is a jet fire. The LFL envelope will decrease in time following the decrease in release rate. In order to account for this decrease, it was decided to distinguish between two stages of the release: 0-20 s associated with direct ignition and 20-140 s associated with delayed ignition. The value 20 s was used as this is the standard duration used to calculate the impact of heat radiation from a fire (RIVM, 1999), (RIVM, 2009). The duration of the second stage (two minutes) is somewhat arbitrary, but in line with the approach followed for high-pressure gas transportation lines (RIVM, 2014a).

## Ignition probabilities

Probably the most difficult part of the investigation was the derivation of ignition probabilities. As the method is used for land-use planning, the method must be conservative for delayed ignition by possibly new ignition sources outside the site boundary. In the Dutch ‘free field approach’ it is assumed that a flammable cloud will always ignite if the LFL contour is (partly) outside the site perimeters. This conservative assumption has the advantage that the construction of new buildings in future will not lead to an increase of the calculated risk. If the calculation would have to be done with the actual, present ignition sources, the consequence is that the construction of new buildings (ignition sources) outside the plant boundary would increase the calculated risk, therefore would invalidate the earlier risk outcomes and thereby would invalidate the land-use plans derived from these outcomes.

As delayed ignition is assumed to occur always, the main challenge was to derive a probability of immediate ignition and to associate time frames with immediate and delayed ignition. Though substantial information on ignition probabilities is available in the public literature, most notably the ignition probability review carried out by the Energy Institute (Energy Institute, 2006), the desired information was difficult to find. Most of the data found in literature suffer from one or more of the following restrictions:

- Data for ‘gas releases’ have been derived from LPG releases. As it is generally assumed that ignition probabilities for natural gas are lower than for LPG, the usefulness of these data for natural gas releases is unknown.
- An overall ignition probability is derived for natural gas, but no distinction is made between immediate ignition and delayed ignition.
- Conditional probabilities for immediate and delayed ignition are provided without addressing the release rate or the number of ignition sources within the LFL envelope.

These and other issues with applying data from commonly used sources, including the look-up correlations developed by the UKOOA, which are reproduced in tables by the OGP (OGP, 2010), are discussed in more detail in (Pesce, 2012).

Overall, the available information on immediate ignition versus delayed ignition and self-ignition versus ignition by remote objects was not suited for implementation in the method. It was therefore decided to use ignition probabilities that are already in place for general Seveso companies (RIVM, 2009). It is recognised that the reliability of these ignition probabilities is limited and that updating these probabilities should be considered when new reliable information becomes available in the public domain.

## Example calculation

The QRA method for on-shore natural gas production and processing sites was applied to the example shown in Figure 1. The main outcomes are presented here in terms of individual risk contours.

The area where the probability of fatality exceeds 1 in a million per year (IR $10^{-6}$) is shown in Figure 6. The red line shows the overall risk for all scenarios and is located at 50 to 70 m distance from the site boundary, depending on the direction. In addition, the risks for the subset of scenarios associated with the production wells are shown in blue and the risks associated with downstream and upstream releases from on-site installations are dotted. It can be easily observed that the location of the overall $10^{-6}$ contour is determined by the downstream releases from installations. This is to be expected, as the back flow from the transportation pipeline (12") is much larger than the inflow from the two production wells (5.25" each).

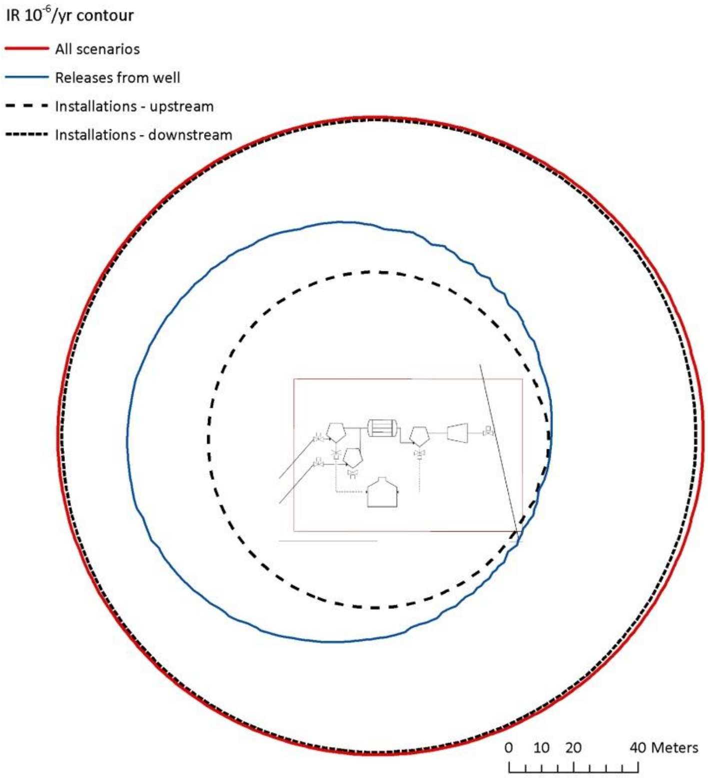


**Figure 6 Risk contours for provided example. No ESD is assumed.**

In Table 5, the release frequencies and consequence outcomes are shown for the most important release scenarios. The distance to the heat radiation level of 10 kW/$m^2$ is the (downwind) distance where the probability of fatality is 1%, and is the maximum effect distance used in the QRA. Noteworthy are the following observations:

- For the blowout during production, a vertical release direction is used. As a result, the effect distances are relatively low compared to the release rate.
- The effect distances are highest for the rupture of 8" pipelines or 8" pipe connections with flow from the downstream side of the facility. The release rates from the downstream direction are higher than those for the upstream direction because the feed from the 12" transportation pipeline is substantially larger than the feed from the two 5.25" production wells.

- If it is desired to reduce the risk, the focus should be on limiting the inflow from the transportation pipelines. This can be accomplished by installing a non-return valve or an ESD valve between the installations and the transportation pipeline. Without inflow from the transportation pipeline, the release rates for the second time frame (20-140s) will be greatly reduced. Given the large differences in probability of ignition for direct and delayed ignition, the resulting IR $10^{-6}$ contour will then be only marginally larger than the contour for the releases from the production well in Figure 6.

**Table 5 Cumulative release frequencies and consequence outcomes for the most important scenarios**

| Release scenario | Ignition | Contribution | Frequency ($yr^{-1}$) | Release rate (kg/s) | Distance to 10 kW/m² (m) |
|---|---|---|---|---|---|
| Prod. Blowout | Early | | $5.9\times10^{-6}$ | 138 | 84 |
| Prod. Blowout | Late | | $6.0\times10^{-5}$ | 78 | 65 |
| Rupture 5.25" | Early | upstream | $4.5\times10^{-7}$ | 24 | 72 |
| Rupture 5.25" | Early | downstream | $4.5\times10^{-7}$ | 83 | 122 |
| Rupture 5.25" | Late | upstream | $4.6\times10^{-6}$ | 13 | 55 |
| Rupture 5.25" | Late | downstream | $4.6\times10^{-6}$ | 50 | 99 |
| Rupture 8" | Early | upstream | $2.3\times10^{-7}$ | 60 | 107 |
| Rupture 8" | Early | downstream | $2.3\times10^{-7}$ | 115 | 140 |
| Rupture 8" | Late | upstream | $2.3\times10^{-6}$ | 28 | 78 |
| Rupture 8" | Late | downstream | $2.3\times10^{-6}$ | 60 | 107 |

## Application of the method to real cases

Prior to implementing the final method (RIVM, 2014b) in official legislation, a draft version of the method was tested for 1 natural gas production site, 9 natural gas processing sites and 14 natural gas transportation sites. The aim of the test was two-fold. Firstly, the test was used to determine if the method was clear and not subject to personal interpretation between users. Secondly, the test was used to study the outcomes of the method for important sites. These outcomes would provide insight in the costs involved with implementing the method in legislation.

The persons involved found that the method was to a large extent clear and that – after some training – it was easy to apply. It should be noted however that most users had already seen and used earlier (draft) versions of the method. The amount of time required to carry out a QRA is slightly larger than for general Seveso sites, because the number of release scenarios that must be modelled has increased (four subscenarios for each rupture, see Table 2). It was believed however that this extra effort was acceptable in the light of the reliability and practicality of the outcomes. A few topics for further clarification were identified and implemented in the final version of the method.

The size of the risk contour used for land-use planning (IR $10^{-6}$ per year) depends on the number of aboveground installations, on the diameters of the aboveground pipelines and on the pressure and diameter of the feed lines. As a result, the contour size varied considerably between the different sites. For gas processing sites, the distance from the site boundary to the IR $10^{-6}$ contour was typically between 100 m and 300 m. The largest distance was 550 m. Gas transportation sites often have larger IR contours when compared to processing sites. This can be explained by the larger diameters of the pipelines involved. Distances for gas transportation sites were between 200 m and 400 m. One underground gas storage with on-site gas processing and pipe connections with the national grid, had an IR $10^{-6}$ contour with a maximum distance to the site boundary of 700 m.

For gas processing sites, the size of the IR $10^{-6}$ contour was typically comparable to or slightly smaller than it had been in earlier calculations using non-standardised methods. For gas transportation sites, the size of the contour increased substantially. The operator confirmed however that the new method gave better results than the (non-standardised) method they had used before, and that it was feasible to implement the new contours in spatial plans.

Because the outcomes of the method were deemed acceptable by all parties involved, the decision was made to implement the method in (official) legislation in 2015.

## Discussion

The process of drafting a QRA method that will give the same results for the same situations, without too much interpretation by the risk analyst, revealed that consequence calculation for natural gas facilities is by no means easy, even though it receives little attention in literature. Some of the encountered difficulties have been described in the previous sections, for example, the release rate calculation and ignition probability. Other aspects that emerged in the process but have not yet been addressed are:

- What consequence events should be used if the Loss of Containment installation is isolated by Fast Closing Valves within seconds? What is the impact of the closing of these valves on the probability of ignition?
- How reliable are the outcomes of discharge models and jet fire models for combined natural gas and condensate streams?
- For which underground or mounded pipelines can a vertical release direction be assumed, in particular: how does the release direction depend on ground cover? And what is the influence of the crater on the jet fire? The information available in the public domain is very limited.
- What is the influence of design parameters and safety management on the release frequency, and how can the influence be quantified?

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