National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Reference Manual Bevb Risk Assessment

Guidelines for calculating external risk for transporting hazardous substances through pipelines

RIVM report 2022-0169

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Synopsis

Reference Manual Bevb Risk Assessment

Guidelines for calculating external risk for transporting hazardous substances through pipelines

The Dutch government has defined standards for the transportation of hazardous substances by pipeline. These standards are laid down in the External Safety of Pipelines Decree (Besluit externe veiligheid buisleidingen), which seeks to keep the risks of accidents involving the transportation of hazardous substances by pipeline within acceptable limits. The Decree lays down rules for the design and operational use of pipelines, as well as spatial planning restrictions for areas surrounding pipelines with a view to limiting the consequences of potential accidents.

Pipeline owners must provide risk calculations to demonstrate that the risks of incidents involving hazardous substances fall within the specified limits. Local authorities must also provide calculations to substantiate the permissibility of any new spatial planning initiatives. In both cases, the risks are calculated using the Reference Manual Bevb Risk Assessment.

The Reference Manual Bevb Risk Assessment sets out the method for calculating the risk to the surrounding area of transporting hazardous substances by pipeline. There are modules for different types of hazardous substances, with each module containing a description of the software to be used for the risk calculation.

The calculation method for pipelines was updated in 2020 in anticipation of the new Environment and Planning Act. The new calculation method, incorporating the latest insights, is available on the RIVM website.

Publiekssamenvatting

Handleiding Risicoberekeningen BevB

Richtlijnen voor het berekenen van externe-veiligheidsrisico's van het vervoer van gevaarlijke stoffen per buisleiding

Voor het transport van gevaarlijke stoffen via buisleidingen heeft de Nederlandse overheid normen bepaald. Deze staan in het Besluit externe veiligheid buisleidingen (Bevb). De normen moeten ervoor zorgen dat de risico's van ongevallen met gevaarlijke stoffen bij buisleidingen binnen acceptabele grenzen blijven. Het Bevb bevat regels voor het ontwerp en de bedrijfsvoering van de buisleidingen. Ook legt het beperkingen op aan de ruimtelijke ordening in de omgeving van de buisleidingen, zodat de gevolgen van een eventueel ongeval beperkt blijven.

Eigenaren van leidingen moeten met risicoberekeningen aantonen dat de risico's van incidenten met gevaarlijke stoffen binnen de gestelde grenzen blijven. Bij nieuwe ruimtelijke ontwikkelingen moeten overheden met een berekening de toelaatbaarheid van de ontwikkeling verantwoorden. In beide gevallen worden de risico's berekend met de Handleiding Risicoberekeningen Bevb.

De Handleiding Risicoberekeningen Bevb beschrijft de methode om het risico voor de omgeving te berekenen van het vervoer van gevaarlijke stoffen via buisleidingen. De handleiding bevat modules voor verschillende typen gevaarlijke stoffen. In die modules is ook beschreven welk rekenpakket gebruikt moet worden om de risico's te berekenen.

Het rekenvoorschrift voor buisleidingen is in 2020 bijgewerkt met oog op de komst van de nieuwe Omgevingswet. Het nieuwe rekenvoorschrift is beschikbaar op de website van RIVM en bevat de meest recente inzichten.

Contents

Introduction

Background

In Dutch external safety policy, a quantitative risk analysis (hereinafter referred to as QRA) is the means to identify the risks for local residents as a result of the transport of hazardous substances[1] through pipelines. Simply put, a QRA calculates the risk of death as a direct result of an incident with hazardous substances, for locations in the vicinity of a pipeline. It is also calculated how likely it is that a group of people of a certain size will die as a result of such an incident. The risks are determined by the geographic location of the pipeline, the properties of the pipeline, the nature of the transported substances, the transport conditions and the nature of the environment. The criteria for assessing the acceptability of risks for pipelines containing hazardous substances are laid down in the External Safety of Pipelines Decree (hereinafter: Bevb) [1].

A QRA must be transparent, verifiable, robust and valid [2]. It is therefore of great importance that each QRA is carried out on the basis of the same models and principles. This document bundles the information that is needed to carry out a QRA for the external safety risks of pipelines for the transport of hazardous substances.

Objective, target group and demarcation

The objective of this manual is to provide a clear framework for carrying out quantitative risk analyses for the transport of hazardous substances through pipelines as well as to provide the necessary background and basic information. This manual is intended for anyone who is professionally involved in external safety of hazardous substances pipelines and in that context performs or assesses a quantitative risk analysis.

This manual lays down how the risks of transporting hazardous substances through pipelines must be analysed in accordance with the current policy. Deviating from this is only possible in special cases and well motivated. Any change in the method for calculating risks must be validated and approved [2]. For example, additional safety measures must be valued on the basis of case studies, analogues or expert judgement.

The risk approach is applied to environmental decisions (such as zoning plans and environmental permits) and infrastructural decisions. The use of this manual for calculating external safety risks is legally anchored in the External Safety of Pipelines Order (hereinafter: Revb). Calculation programs are required to perform risk calculations. This manual describes which calculation programs are used. This concerns the CAROLA calculation programme for high-pressure natural gas pipelines and the SAFETI-NL calculation programme for other pipelines that fall under the scope of the External Safety of Pipelines Decree (Bevb).

[1] In the calculation method Bevb risk is understood to mean: the risk of (acute) death as a result of a accident involving dangerous substances. Effects are defined as: acute mortality due to exposure to toxic substances, heat radiation or overpressure.

Reading guide

This manual consists of four modules. Module A explains the legal framework. Module B describes the calculation method for high-pressure natural gas pipelines. Module C describes the calculation method for pipelines with petroleum products and flammable liquids. Module D describes the calculation method for chemical pipelines (other than high-pressure natural gas pipelines or pipelines with petroleum products and flammable liquids).

Information

In practice, there may be situations where the application of this manual can lead to questions. Questions and comments can be addressed to RIVM, via the email address safeti-nl@rivm.nl.

References:

[1.] Decree on external safety of pipelines. Available via https://wetten.overheid.nl/BWBR0028265/2018-03-31

[2.] Protocol adjustment calculation methods External Security. RIVM report 6205500009. 2012. Available via Protocol adjustment calculation methods External Security (rivm.nl).

Module A - Legal framework

Version 3.2
01 January 2021

1 Legal framework

1.1 External Safety of Pipelines Decree (Bevb)

The External Safety of Pipelines Decree [Besluit Externe Veiligheid Buisleidingen, hereinafter referred to as Bevb] describes risk standards related to external safety to which operators of pipelines transporting hazardous substances must comply. These operators sometimes perform high-risk activities in the vicinity of people or groups of people. The decree aims to limit those risks and thus offers citizens a minimum level of protection. It obliges operators to take account of external safety before using pipelines and municipal authorities to take external safety into account when formulating land-use plans.

1.2 External Safety of Pipelines Order (Revb)

The External Safety of Pipelines Order [Regeling Externe Veiligheid Buisleidingein, hereinafter referred to as Revb] includes rules concerning risk calculations for pipelines. A calculation is also required for the societal risk accountability in the area of influence. The Revb stipulates the use of the Bevb calculation method for determining the individual risk and societal risk for the pipeline operators.

1.3 Use of an alternative calculation method

The Revb arranges the generic acceptance of alternatives that are equivalent to the Reference Manual Bevb Risk Assessments and CAROLA for high-pressure natural gas pipelines and SAFETI-NL for petroleum products and chemical pipelines. The use of a different calculation method needs to be approved by the Minister of Infrastructure and Water Management(hereinafter referred to as I&W) who, after advice has been obtained from RIVM, passes a resolution. The Minister's resolution is a resolution as defined in the General Administrative Law Act [Algemene wet bestuursrecht , hereinafter referred to as Awb]. Heading 4.1 Provisions [Beschikkingen] of the Awb applies to the resolution of the approval or rejection of the calculation method. Regulations are recorded under this heading with regard to, among other things, the application for approval, the decision-making period and the preparation of the approval or its withholding. An objection or appeal may be lodged against this decision. Chapters 6 and 7 of the Awb relating to objection and appeal are therefore applicable in this procedure.

Applications for using an alternative calculation method must be sent to the Minister of I&W, with respect to the RIVM, Centre for Environmental Safety and Security, PO Box 1, 3720 BA Bilthoven. A comprehensive procedure for such an application and the evaluation of different calculation methods can be downloaded from RIVM's website.

Module B - High pressure natural gas pipelines

Version 3.2
01 January 2021

Introduction

The relevant laws and regulations introduced by the Ministry of Infrastructure and Water Management concerning underground high-pressure natural gas transport pipelines are based on the calculation method for determining individual risk and societal risk, developed by NV Nederlandse Gasunie and RIVM and approved by the Ministry. The risk calculations were originally based on the generally not freely accessible PIPESAFE calculation package (version 2.14.0) [1], [2]. CAROLA (Computer Applicatie voor Risicoberekeningen aan Ondergrondse Leidingen met Aardgas) {*Computer Application for Risk Calculations for Underground Natural Gas Pipelines*} [3] is a freely available derivative of PIPESAFE and replaces the PIPESAFE model as the calculation standard. The results from CAROLA match the results from PIPESAFE and are in accordance with the aforementioned and approved calculation method. The CAROLA calculation package is the Dutch default package for underground high-pressure natural gas transport pipelines and must be used for situations in the Netherlands.

The use of CAROLA is required to obtain the individual risk distances and societal risk values that are mentioned in the relevant laws and regulations related to underground natural gas transport pipelines.

This module describes the basic principles for calculations using the CAROLA calculation package. In addition, it describes how a risk assessment should be carried out using the CAROLA calculation package.

The risk assessment method for underground high-pressure natural gas transport pipelines is described in a RIVM report [4]. This report discusses the scenarios, failure frequencies, source term and the effects that are included. Additional information about the risk assessment method is given in a Gasunie report [5] and a NAM report [6]. All reports can be accessed via the RIVM website.

2 Calculation method

2.1 Pipeline types

The CAROLA calculation package allows calculations to be performed for underground high-pressure natural gas transport pipelines. It must be possible to qualify the natural gas as one of the gases mentioned below. When this is not the case, it may not be possible to determine the risks of the pipelines concerned using this module of the Reference Manual Bevb Risk Assessments and using CAROLA. The risks will then have to be assessed based on the best scientific insights.

2.1.1 Dry gas pipelines

Dry gas pipelines contain treated natural gas. Dry gas means the gas does not condensate at -20 °C at atmospheric pressure.

2.1.2 Wet gas pipelines

Wet gas pipelines are pipelines in which, next to natural gas, other condensates are present as well. For wet gas pipelines with a maximum Condensate Gas Ratio (CGR) of 80[2], the same method applies as for dry gas pipelines [7].

To perform risk calculations for pipelines containing wet gas with a CGR greater than 80 you must specifically check whether the CAROLA calculation package is suitable for this, or can be made suitable. If this is not the case the calculations, depending on the properties of the wet gas, must be performed in accordance with the Reference Manual Bevb Risk Assessments Module C, Pipelines carrying petroleum products or the module in the Reference Manual Bevb Risk Assessments, Module D Pipelines carrying other substances.

The risk calculation takes account of 'damage by third parties' and 'corrosion' causes of failure for dry gas pipelines. For wet gas pipelines, internal corrosion is an additional cause of failure.

There are two preconditions under which it is estimated that no significant contribution can be expected from internal corrosion:

- Internal corrosion is ruled out when duplex steel is used and the failure frequency can be derived in the same way as for dry gas pipelines.
- If carbon steel is used as a material, a corrosion inhibitor and a corrosion layer are applied to the wall thickness. The corrosion layer that is used in the wall thickness of the pipeline must not be included in the calculations of the failure frequencies for the 'damage by third parties' and 'corrosion' causes of failure. If a corrosion inhibitor is not used consistently, a specific check must be carried out to determine the contribution from internal corrosion. The calculation package cannot be used immediately. When specific measures concerning maintenance and inspection are implemented and the operator is able to demonstrate that wall

[2] Condensate Gas Ratio (CGR) ≤ 80 m^3 condensate /10^6 Nm^3 gas.

thickness does not decrease, then an exception can be made to not include the corrosion layer in the wall thickness. The Nederlandse Aardolie Maatschappij BV has demonstrated this for its pipelines [8], [9].

2.1.3 *High calorific gas*

By default CAROLA uses the so-called H-gas (high calorific gas), with a density of 0.82 kg/m^3 and a net calorific value of 36.4 MJ/m^3 in its calculations.

2.1.4 *Acid gas pipelines*

In addition to natural gas, acid gas pipelines also contain hydrogen sulphide (H_2S). It has previously been deduced that if the percentage of H_2S is less than 4.3%, the toxic component is not included in the risk calculations and in such cases CAROLA is suitable for determining the risks in full. It follows from [10] that the flammable properties determine the risk even up to 12 vol% hydrogen sulphide.

2.2 Validation limits of calculation package CAROLA

The CAROLA calculation package can be used for underground high-pressure natural gas transport pipelines with a diameter from 2 inches up to and including 48 inches. Strictly speaking, the models used have been validated from 8 to 100 bar, although it is expected that it is justified to use the models to a minimum of 150 bar.
The CAROLA package can, however, calculate pipelines to a maximum of 300 bar. In pipelines with a pressure higher than 150 bar heavy gas dispersion could occur, among other things, (depending on the composition of the gas) and for these pressures it cannot be justified that the CAROLA package produces a realistic estimate of the risks.

3 Model parameters

3.1 Introduction

A risk calculation using the CAROLA calculation package is in accordance with the specified calculation method [4], [7]. When performing the calculations, a number of choices have to be made and a number of parameter values have to be entered. This chapter describes these selections and the parameters relevant to the risk assessments. The description distinguishes between two types of parameters:

Category 1: General parameters that the pipeline operator and user cannot change, but which are characteristic of a QRA calculation for underground pipelines. These parameters are set out in section 3.3.

Category 2: Project-specific parameters to align the calculation with location-specific circumstances. These are parameters that the user enters or data that the pipeline operator supplies to the user. These are set out in section 3.4.

In addition, there are other parameters that the user cannot modify, but that are part of the calculation model, and parameters that do not affect the calculation results, but only determine the presentation of (intermediate) results. These parameters are set out in the documentation for the calculation package.

3.2 Modelling scenarios

For underground high-pressure natural gas transport pipelines, one representative scenario is prescribed [4], see Table 1.

Table 1 High-pressure natural gas transport pipelines scenario.

Scenario
Rupture

Notes:

- Although leaks will occur more frequently than ruptures, their contribution to the risk is negligibly small compared to ruptures. This has been demonstrated by calculations using PIPESAFE [5]. Therefore, leaks are not included in the risk calculations for underground natural gas transport pipelines and only ruptures are considered.
- The risk determining ruptures are mainly a consequence of third party excavation work [5]. In the risk assessment method for natural gas transport pipelines, this is specifically taken care of. In addition, the contribution from the failure of a pipeline due to corrosion is included in the risk assessment method. Implementing additional measures such as internal inspection can reduce or rule out the contribution from corrosion [4].
- Because the probability of a rupture is mainly determined by excavation work, the probability of damage depends on the depth of the pipeline. Whether or not damage results in a rupture then depends on the diameter, wall thickness, pressure, type of steel and impact resistance.

3.3 QRA-specific parameters

The parameters in this category are general parameters that cannot be changed.

3.3.1 Direction of the outflow

The default outflow direction for underground pipes is vertical.

3.3.2 Time varying release and probability of ignition

Given that the outflowing gas ignites, the default calculation uses a 0.75 probability of immediate ignition and a 0.25 probability of delayed ignition. The calculation uses a time-averaged outflow rate, assuming a 20-second exposure. For immediate ignition the calculation uses an average flow rate over the first 20 seconds after the line rupture occurs; for delayed ignition the calculation uses the time-averaged flow rate over the period from 120 to 140 seconds.

Table 2 Immediate and delayed ignition.

Time-period averaged outflow rate	Fraction of ignition time
0 – 20 s (immediate ignition)	0.75
120 – 140 s (delayed ignition)	0.25

The probability of ignition depends of the diameter and the pressure in the pipeline [4], [5]. For illustration purposes, Table 3 gives the probability of ignition for pipelines with a diameter from 4 up to and including 16 inches at 40 bar pressure and greater than 16 inches at 66.2 bar pressure.

Table 3 Examples of probabilities of ignition for pipelines with a diameter up to 48 inches.

Pipeline diameter (inches)	Pressure (bar)	Probability of ignition
4	40	0.18
6	40	0.19
8	40	0.20
10	40	0.22
12	40	0.24
14	40	0.25
16	40	0.27
18	66.2	0.28
20	66.2	0.33
24	66.2	0.44
30	66.2	0.65
36	66.2	0.80
42	66.2	0.80
48	66.2	0.80

3.3.3 Pressure loss as a result of valves and bends

Pressure loss in a pipeline due to the presence of valves, joints and bends is not taken into account in the calculation.

3.3.4 *Roughness length of the surrounding area*

The roughness length is an (artificial) length measurement that indicates the impact of the surrounding area on wind speed. The default roughness of the surrounding area to determine the wind profile is 0.1 metres. The description of the surrounding area is included in Table 4.

Table 4 Description of terrain type with roughness length.

Description of surrounding area	Roughness length
Low vegetation; large obstacles here and there, x/*h* > 20	0.10 m

Note:
x is a typical distance between obstacles upwind and *h* is the typical height of the obstacles.

3.3.5 *Weather station and parameters*

The calculation package automatically selects the weather station representative of the location where the rupture occurs. This will be one of the weather stations shown in *Table 5*.

Table 5 Weather stations.

Name					
Beek	Eelde	Hoek van Holland	Rotterdam	Twente	Volkel
Deelen	Eindhoven	Ijmuiden	Schiphol	Valkenburg	Woensdrecht
Den Helder	Gilze-Rijen	Leeuwarden	Soesterberg	Vlissingen	Ypenburg

The values used in CAROLA for a number of meteorological parameters are given in Table 6. The values are yearly averages.

Table 6 Default values used for a number of meteorological parameters.

Parameter	Day default value	Night default value
Ambient temperature	9 °C	9 °C
Gas temperature	9 °C	9 °C
Atmospheric pressure	101,510 N/m^2	101,510 N/m^2
Relative humidity	83 %	83 %
Fraction of a 24-hour period	0.44 (08:00 – 18:30)	0.56 (18:30 – 08:00)

Note:
The default values used in CAROLA are the same as the values in the high pressure natural gas transport pipelines consequences analysis and have been taken from the Purple Book [11]. They differ from the default values in the Reference Manual Bevi Risk Assessments [12]. The parameters included in Table 6 hardly affect the relevant effect (being thermal radiation) of a rupture in an underground high-pressure natural gas transport pipeline.

3.3.6 *Height for calculating the effects*

The 2-dimensional thermal radiation profile is calculated at a height of one metre in accordance with the Purple Book [11] and the Reference Manual Bevi Risk Assessments [12].

3.3.7 *Lethality*

The probability of dying, P_{lethal}, is calculated using a probit, Pr,

$$P_{lethal} = 0{,}5 \times \left[1 + erf\left(\frac{\mathrm{Pr}-5}{\sqrt{2}}\right)\right] \qquad (1)$$

where

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \qquad (2)$$

The probability of dying, P_{lethal}, of exposure to heat radiation (jet fire) is given by the probit relationship:

$$\mathrm{Pr} = a + b \ln\left(\int Q^c \, dt\right) \qquad (3)$$

where

Pr	probit associated with the probability of dying	(-)
Q	thermal radiation at time t	(kW m^{-2})
t	exposure time	(s)

and probit constants a = -12.8; b = 2.56; c = 1.33.

With a time-averaged flow rate and therewith a time varying thermal radiation profile and an exposure time of 20 seconds, reduces the above formula to:

$$\mathrm{Pr} = -12.8 + 2.56 \cdot \ln\left(Q^{1.33} \cdot 20\right) \qquad (4)$$

The minimum value of P_{lethal} that is still included in the calculation is 0.01. The calculation of the probability of dying for the individual risk and for the societal risk is given in Table 7.

Table 7 Probability of dying for flammable substances - thermal radiation

Area	**Individual Risk**	**Societal Risk Inside**	**Societal Risk Outside**
thermal radiation ≥ 35 kW m^{-2}	1	1	1
thermal radiation < 35 kW m^{-2}	P_{lethal}	0	0.14 × P_{lethal}

Note:
To determine the probability of dying for people outside, the calculation of the societal risk includes a protection factor of 0.14 for clothing.

3.3.8 *Wind turbine influence*

The effect of wind turbines must be included in the risk determination. However, at this time it is not possible to include the effect of wind turbines in the vicinity of underground high-pressure natural gas transport pipelines directly in CAROLA as a parameter in the risk calculation. A method for determining the effect of wind turbines is specified in [13].

3.4 Project-specific parameters

The parameters in this category can be modified to align the calculation with the specific conditions of the pipeline and the surrounding area.

3.4.1 Location of the outflow

The individual risk and the societal risk are determined by integrating the product of failure frequencies and lethality over the length of the pipeline. Therefore, it is important that the pipeline is properly mapped, particularly where it concerns the specific location of the route (x and y coordinates) and the parametrisation of the pipeline per coordinate (diameter, pressure, wall thickness, steel type, cover, etc.).

The (x, y) coordinates required for a pipeline are supplied by the pipeline operator. The risk calculations take the varying location-specific pipeline characteristics into account. When there is change in diameter, pressure, wall thickness, steel type or cover over the pipeline, a new coordinate with associated characteristics should be included. In addition, new coordinates must be included for bends or when there is a change in location-specific risk reduction measures that have been/are to be taken. A transition in a pipeline characteristic occurs at the coordinate where the value differs from the value of at the preceding coordinate. The characteristics are thus not interpolated between two successive coordinates.

To draw a representative risk contour to for a long transport pipeline, the pipeline coordinates used in the risk calculation should be at a regular distance from each other. The number of coordinates should be sufficiently high to avoid the risk calculations being dependent on the number of coordinates. To this end, the calculation package performs its own interpolation when the distance between two successive pipeline coordinates is more than 10 metres.

3.4.2 Topographic maps

When using the calculated intervals or contours, it is important that the accuracy of the mapping material corresponds with the intended use. Since distances and contours are relevant for land-use planning, the use of the Large Scale Standard Map of the Netherlands (scale 1:100 – 1:5000) is recommended. The use of a topographic map at a scale of 1:10,000 or 1:25,000 is permitted only for specific circumstances (for example, if calculations are not intended for land-use planning). The coordinates must be entered manually on the topographic maps in the package.

3.4.3 Area of interest

The area of interest is the area in which a spatial development is/has been projected next to a pipeline or where a modification to an existing or new pipeline is planned. The area of interest must fit within a 10 × 10 km^2 square. An example of an area of interest is given in Figure 1. The figure also includes the inventory distance (ID) for the societal risk. This inventory distance is defined by the 1% lethality distance and is determined by the calculation package itself. The area of interest and the inventory distance determine the total length of the pipeline that should be included in the societal risk calculations.

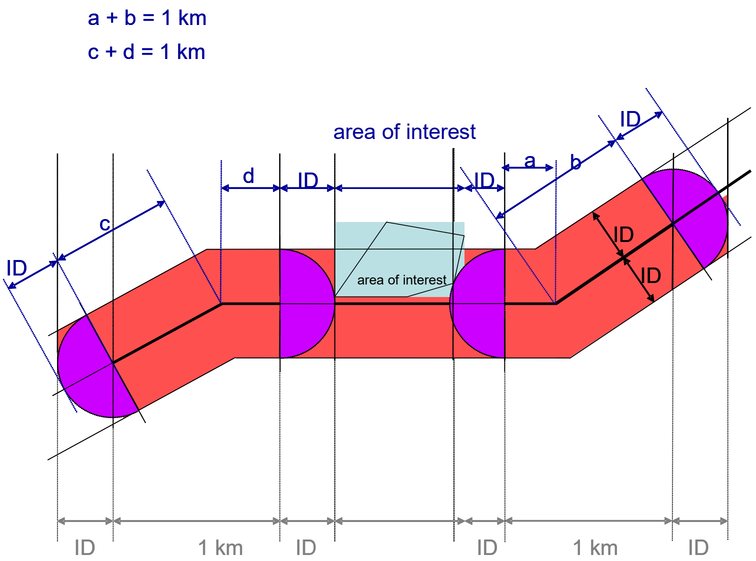

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Figure 1 Area of interest, inventory distance (ID) and total pipeline length that should be included in the societal risk calculations.

3.4.4 *Population*

Three different types of population can be entered in the CAROLA calculation package: residential, working and events. To calculate the societal risk correctly, the population within the area of influence of the societal risk (defined by the inventory distance), must be entered in the model. There are two ways to specify the population details within the area of influence:

- Loading the text files with the population
- Manually creating polygons with population

When loading a text file, the user is required to select the type of population (residential, working or events). When doing so a number of default parameters are displayed (Table 8). When the type of population and the corresponding default parameters are displayed, the user must either approve these default settings or change the population type or the default values respectively. The same parameter values and limitations are applicable for the user-generated polygons.

Table 8 Default residential, working and events values.

Default values	**Residential**	**Working**	**Events**
Percentage present during the day	50%	100%	100%
Percentage present during the night	100%	0%	100%
Percentage outside during the day	7%	7%	7%
Percentage outside during the night	1%	1%	1%
Percentage of time present in daytime during the year	100%	100%	1%
Percentage of time present at night during the year	100%	100%	1%

Table 9 Permitted values for residential, working and events.

Permitted values	Resi-dential	Work-ing	Events
Percentage present during the day	0-100%	0-100%	100%
Percentage present during the night	0-100%	0-100%	100%
Percentage outside during the day	0-100%	0-100%	0-100%
Percentage outside during the night	0-100%	0-100%	0-100%
Percentage of time present in daytime during the year	100%	100%	0-50%
Percentage of time present at night during the year	100%	100%	0-50%

Notes:

- The user cannot change the grey values in Table 8.
- A change to one polygon or text file has no consequences for other text files or polygons.
- Polygons can be copied and the characteristics can be modified. This allows residential, working and events to be defined within the same area. Polygons can overlap other polygons and points in a text file that has been loaded. People defined within polygons are assumed to be evenly distributed.
- By default daytime is 10.5 hours and night time is 13.5 hours. In addition, the default protection factor for clothing is set to 0.14. The user cannot modify these default values. These values, together with the values that are assigned to the present population, the proportion of the people that are outside and the percentage over time, are included in the societal risk calculations. The presence percentage for people and the percentage of people outside have an effect on the number of fatalities, while the time percentage has an effect on the frequency.
- All population data can be saved and reloaded.

3.4.4.1 Modelling people at events

Events represent locations where a large number of people are present during shorter periods of the year. People who are only present for part of the year (or of the daytime period), such as in recreational areas or at events, must be included in the calculation if the contribution to the societal risk is relevant. The inclusion of such groups in the CAROLA calculation package is handled by defining time periods with different numbers present, taking the required accuracy into account. Therefore, the time fraction of the year that the activity takes place has a range of 0 - 50% for events (see Table 9).

Example: if a stadium has to be modelled that is only occupied for 4 hours a week in the daytime period, then the time fraction is equal to $4/(168\times10.5/24) = 0.054$, which concurs to a daytime percentage of 5.4%. A comprehensive example is shown in the box below.

It has been decided to not allow events to take place at the same time, in the calculation package. If more than one event has to be created, the people involved in these individual events are therefore never present at the same time. This is why the sum of the time percentages for all events must be less than or equal to 100%. If the sum is greater than 100%, the user is warned that the events overlap each other in time. The calculation package will then ask for the number of activities or the corresponding time percentages to be adjusted. The calculations can only proceed after this has been done. The residents and workers are always present during events.

The FN points for the societal risk must be calculated for:

- All combinations of wind speed and direction during the day and night.
- All combinations of residents (R), workers (W) and events (E).

Naturally, all FN points have to be cumulated into an FN curve.

Firstly, the failure frequency f is divided into day and night
$f_{day} = f \times$ day time-period / 24
$f_{night} = f \times$ night time-period / 24

Secondly, the scenarios with a frequency f_{day} and f_{night} are divided for all combinations of wind speed (4) and wind direction (12). This results in 96 scenarios with a frequency $f_{day.1}$…. $f_{day.48}$; $f_{night.1}$…. $f_{night.48}$

These 96 scenarios are then divided for the societal risk calculation by combining them with all combinations of the residents (R), workers (W) and events (E). This is implemented for the incident scenario with a frequency $f_{day.1}$ (all other incident scenarios must be handled in the same way).

The scenario with a frequency $f_{day.1}$ is divided for the following population combinations:

1. Residents (R) and workers (W) present for event E_1
   The total population (P) at an x,y coordinate is equal to $R(x,y) \times F_{rd} + W(x,y) \times F_{wd} + E_1(x,y)$. F_{rd} and F_{wd} are the percentages of the residents and workers present as defined in Tables 8 and 9 (the percentages of the night time-period must be used for a night scenario).
2. The frequency for this base scenario is now: $f_{day.1} \times F_{ed.1}$
   $F_{ed.1}$ is the percentage of time that the event is present on the day during a year (the percentages of the night time-period must be used for a night scenario).
   Residents (R) and workers (W) present for event E_2
   The total population (P) at an x,y coordinate is equal to $R(x,y) \times F_{rd} + W(x,y) \times F_{wd} + E_2(x,y)$ The frequency for this base scenario is now: $f_{day.1} \times F_{ed.2}$
   …
   …

n residents (R) and workers (W) present for event E_i
The total population (P) at an x,y coordinate is equal to:
$R(x,y) \times F_{rd} + W(x,y) \times F_{wd} + E_i(x,y)$

The frequency for this base scenario is now: $f_{day.1} \times F_{ed.i}$

n+1 residents (R) and workers (W) present when no event is taking place

The total population (P) at an x,y coordinate is equal to is R(x,y) × F_{rd} + W(x,y) × F_{wd}

The frequency of this base scenario is: $f_{day,1} \times (1 - \sum_{i=1}^{n} F_{ed,i})$

The total number of scenarios for which *f*N points must be calculated is equal to 96 × (*n*+1). For the sum of all events *i*, the following limitations apply for the factors F_{ed} and F_{en} :

$$\sum_i F_{ed_i} \leq 100\% \quad \text{and} \quad \sum_i F_{en_i} \leq 100\%$$

3.4.5 *Pipeline file characteristics*

The pipeline file comprises rows that include the relevant pipeline characteristics. These characteristics and their corresponding permitted values are given in Table 10. A comprehensive description of the technical limits for the input data is included in section 6.2.

Table 10 Structure of the pipeline file.

Characteristics	Permitted values
x coordinate	National triangulation system coordinate
y coordinate	National triangulation system coordinate
Stationing (m)	Distance from the start of the pipeline
Diameter (mm)	50 – 1234
Pressure (barg)	16 – 300
Wall thickness (mm)	2 – 40
Yield stress (N/mm^2)	180 – 552
Depth (m)	0 – 30
Charpy energy (J)	14; 24; 40; 70
Additional ground cover (m)	0 – 30
Number of the mitigating measure taken from Cluster 2	20 – 29
Number of the mitigating measure taken from Cluster 3	30 – 39
Number of the mitigating measure taken from Cluster 4	40 – 49
Number of the mitigating measure taken from Cluster 5	50 – 59

Notes:
- For new pipelines, the risk for an individual pipeline can be based solely on the diameter, pressure, wall thickness, yield stress, depth and Charpy energy parameters. The effect of any measures applied from Cluster 2, 3, 4 and 5 must not be taken into account in the calculations.
- In CAROLA the period (.) is used as a decimal separator, the separator between columns of characteristics can be spaces, commas or tabs.

- The stationing is a characteristic of every pipeline coordinate. This indicates the distance from the start of the pipeline to the relevant pipeline coordinate in the horizontal plane:
  $$s_{i+1} = s_i + \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2} \qquad (5)$$
  The stationing of each coordinate is therefore fixed and is in principle independent of an excision from the pipeline file of the pipeline operator.
- As far as pressure is concerned, please refer to section 2.2 which shows the pressures for which the CAROLA calculation package has been validated, and the pressures for which calculations can be performed.
- The consequences for spatial planning (IR and SR) of a pipeline with decreasing pressure over time, are established for a single situation.
  - For new pipelines, the basic principle is the design pressure (maximum operating pressure).
  - For existing pipelines, the following basic principles can be used:
    - In line with the basic principle for new pipelines and based on the design pressure (conservative). This could be the case if the pipeline is subject to a permit.
    - The actual (maximum) pressure in the pipeline. Here there must also be a guarantee that the pressure cannot become any higher in future, as a result of connection to a new field for example. For pipelines where additional pressure-relief devices are used, the maximum pressure that is permitted by the additional devices, could also be used.
- The 'additional ground cover' measure is declared by the pipeline operator in meters and is included in the calculation package in the calculation of the failure frequency (see section 6.1 for the preconditions). This measure is denoted as a discrete value of (a multiple of) 0.10 metres.
- The depth and the additional ground cover have a positive value for underground pipelines.
- The calculation uses a minimum of 0.05 meters and a maximum of 2.0 metres for the depth irrespective of any different values in the pipeline file. The depth that is used in the calculation is a combination of the depth and the additional depth that can be included as a measure, where the aforementioned maximums are used.
- The calculation package includes the known combinations of pressure and diameter. If a combination of pressure and diameter is missing, a request can be submitted to RIVM to include it in the underlying tables in the calculation package.
- All pipeline information, together with the name of the pipeline operator, version number of the calculation package and the expiry date are saved in an encrypted file, which the user cannot read or change. The encrypted file also contains a specification of the area of interest. The encrypted file is used as input for the calculation package.
- The risk calculations take account of the varying location-specific pipeline characteristics. When there is change in diameter, pressure, wall thickness, steel type or ground cover over the pipeline,

a new coordinate with corresponding characteristics should be included. Cover transitions of 20 cm or more must be described in the pipeline file. In addition, cover transitions of 10 cm or more that continue over a pipeline distance of 50 metres or more have to be described. New coordinates must be included for bends or when there is a change in location-specific risk reduction measures that have been/are to be taken. A transition in a pipeline characteristic occurs at the coordinate where the value differs from the value at the preceding coordinate in the pipeline file. The characteristics are therefore not interpolated between two successive coordinates.

3.4.6 *Mitigating measures for damage by third parties*

A number of measures can be implemented to reduce the risk for high-pressure natural gas transport pipelines. The measures in this paragraph act on the main cause of failure for natural gas transport pipelines, 'damage by third parties'. The measures are described in detail in the RIVM report [4]. The preconditions are stated in the annex (Chapter 6) to this module. These must be adhered to benefit from the reduction factor for a measure. The pipeline operator is responsible for including any measures in the pipeline file and their Safety Management System (SMS) and Risk Management System (RMS).
The default failure frequencies for damage by third parties can be adjusted, given the measures to be taken and the measures taken using the following formula:

$$\text{failure frequency}_{\text{damage by third parties, adjusted}} = \text{failure frequency}_{\text{damage by third parties}} \times \text{factor} \qquad (6)$$

where:

$$\text{factor} = \text{factor}_{\text{cluster1}} \times \text{factor}_{\text{cluster2}} \times \text{factor}_{\text{cluster3}} \times \text{factor}_{\text{cluster4}} \times \text{factor}_{\text{cluster5}} \qquad (7)$$

For clusters 2 to 5, only one measure can be selected per cluster. These measures are numbered 0 to 9 for clusters 2 to 5, which leads to the measures being numbered from 20 to 59. The factor for clusters 2 through 4 becomes the factor for the measure selected. Cluster 5 has a dependency on Cluster 1. If no mitigating measures are taken for Clusters 2, 3, 4 and 5, the numbers in the pipeline file for these clusters are 20, 30, 40 and 50 respectively, and the corresponding reduction factor is equal to 1.

3.4.6.1 Cluster 1 - regulations and case studies

The measures in Cluster 1 relate to the Excavation Contractors Regulation (Aboveground and Underground Grids Information Exchange, WIBON [14]) (A), the reduction in the basic failure frequency based on case studies (B) and active reminder (C).

A. WIBON legislation	factor:	0.400
B. Case study		
Pipeline operator 1	factor:	0.357
Pipeline operator 2	factor:	1.000
Pipeline operator 3	factor:	1.000

Pipeline operator 4 factor: 1.000
…
Pipeline operator 64 factor: 1.000

C. Active reminder

Pipeline operator 1 factor: 0.833
Pipeline operator 2 factor: 1.000
Pipeline operator 3 factor: 1.000
Pipeline operator 4 factor: 1.000
…
Pipeline operator 64 factor: 1.000

The factors for B and C are recorded based on the name of the pipeline operator. The total factor for a pipeline operator based on measures from Cluster 1 is the product of A, B and C.
Thus, in the current example for pipeline operator 1 the factor for Cluster 1 is equal to 0.4 × 0.357 × 0.833 = 0.119; while for pipeline operators 2 to 64 the factor from Cluster 1 is equal to 0.4 × 1.000 × 1.000 = 0.400.

The values are shown per pipeline operator in Table 11. The values in the table are included in version 1.3 of the CAROLA parameter file.

Table 11. Summary of operator-specific factors for various pipeline operators.

Operator	Cluster 1B Case study	Cluster 1C Active reminder	Mitigating measures for corrosion	Reference
Alliander	1.000	1.000	1.000	
BBL Company VOF	0.357	0.833	0.000	[4], [15]
DELTA Netwerkbedrijf BV	1.000	0.833	0.000	
Essent	1.000	0.833	0.000	
GDF SUEZ E&P Nederland BV	1.000	1.000	1.000	
Nederlandse Aardolie Maatschappij BV	1.000	0.833	0.000	[8], [9]
Nederlandse Aardolie Maatschappij BV – ONEGas	1.000	0.833	0.000	[8], [9]
Noordgastransport BV	1.000	1.000	1.000	
Northern Petroleum Nederland BV	1.000	0.833	1.000	
NV Nederlandse Gasunie	0.357	0.833	0.000	[4], [15]
NV Nuon	1.000	0.833	1.000	
RWE Westfalen-Weser-Ems Netzservice GmbH	1.000	1.000	1.000	
TAQA Energy BV	1.000	1.000	1.000	
Vermilion Oil & Gas Netherlands BV	1.000	1.000	1.000	
Wintershall Noordzee BV	1.000	0.833	1.000	
Zebra Gasnetwerk BV	1.000	0.833	0.000	
Tulip Oil Netherlands BV	1.000	1.000	1.000	

3.4.6.2 Cluster 2 - cover using protective material

This relates to measures where underground cover has been applied to the pipeline.

20. none	factor: 1.000
21. warning tape	factor: 0.599
22. protection plates	factor: 0.200
23. warning tape + protection plates	factor: 0.033
24. reserve	factor: 1.000
25. reserve	factor: 1.000
26. reserve	factor: 1.000
27. warning tape + protection plates | proposed	factor: 0.033
28. protection plates | proposed	factor: 0.200
29. warning tape| proposed	factor: 0.599

3.4.6.3 Cluster 3 - management measures

Management measures relate to the limitation and/or exclusion of excavation work, based on a management agreement with the landowner.

30. none	factor: 1.000
31. agreement, extensive restrictions	factor: 0.010
32. agreement, digging/drilling prohibited	factor: 0.100
33. agreement, limited restrictions	factor: 0.625
34. reserve	factor: 1.000
35. reserve	factor: 1.000
36. reserve	factor: 1.000
37. agreement, limited restrictions | proposed	factor: 0.625
38. agreement, excavating prohibited | proposed	factor: 0.100
39. agreement, extensive restrictions | proposed	factor: 0.010

3.4.6.4 Cluster 4 - physical barriers at ground level

This concerns measures that make clear that excavation work is not allowed.

40. none	factor: 1.000
41. fencing	factor: 0.000
42. embankment	factor: 0.100
43. barrier at ground level	factor: 0.125
44. reserve	factor: 1.000
45. reserve	factor: 1.000
46. reserve	factor: 1.000
47. barrier at ground level | proposed	factor: 0.125
48. embankment | proposed	factor: 0.100
49. fencing | proposed	factor: 0.000

3.4.6.5 Cluster 5 - other measures

The measures in Cluster 5 relate to measures that operate relying on the Excavation Contractors Regulation. One measure can be selected from Cluster 5. The factors for the measures in Cluster 5 depend on the parameter values for A and C, as described in Cluster 1. The following formula applies:

$$factor_{cluster5} = (A \times C)^{-1} / factor_{selected\ measure,\ cluster\ 5} \qquad (8)$$

If no measures are specified for Cluster 5 (in other words: if the number for Cluster 5 in the pipeline file is 50) then the $factor_{cluster5}$ = 1.0.

50. none	-
51. strict supervision of activities	factor: 7.5
52. camera monitoring	factor: 6.5
53. reserved	factor: 1.0
54. reserved	factor: 1.0
55. reserved	factor: 1.0
56. reserved	factor: 1.0
57. reserved	factor: 1.0
58. camera monitoring | proposed	factor: 6.5
59. strict supervision of activities | proposed	factor: 7.5

3.4.6.6 Permitted values

Permitted values for the factors in Cluster 1 to 5:

Cluster 1 factors:	0.000 – 1.000
Cluster 2 factors:	0.000 – 1.000
Cluster 3 factors:	0.000 – 1.000
Cluster 4 factors:	0.000 – 1.000
Cluster 5 factors:	1.000 – 100.0

The values that are assigned to the various mitigating factors (as described in sections 3.4.6.1 through 3.4.6.5) cannot be changed by the user or pipeline operator. These changes can only be implemented by RIVM.

3.4.7 Mitigating measures for corrosion

The default failure frequencies for corrosion are adjusted depending on the pipeline operator:

$$\text{failure frequency}_{\text{corrosion, adjusted}} = \text{failure frequency}_{\text{corrosion}} \times \text{factor} \quad (9)$$

where the factor depends on the pipeline operator:

Pipeline operator 1	factor:	0.000
Pipeline operator 2	factor:	1.000
Pipeline operator 3	factor:	1.000
Pipeline operator 4	factor:	1.000
…		
Pipeline operator 64	factor:	1.000

So for pipeline operator 1 corrosion is ruled out as a possible cause of failure (factor = 0.000) while for the other pipeline operators corrosion must still be considered as a possible cause of failure.
Permitted values for the factor of the corrosion mitigation measures:

factors: 0.000 or 1.000

If specific measures are taken concerning maintenance and inspection and the operator can demonstrate that there is no external corrosion, then this factor can be set to 0. This can for example be done through coating inspections and pig operations. The inspection frequency and the

identification of the pipeline sections specifically targeted by the inspection programme, are the operator’s responsibility [4]. This must be guaranteed and demonstrable within the care system/inspection programme.
Again, the aforementioned factors cannot be changed by the user or the pipeline operator. These changes can only be implemented by RIVM.

4 Procedure for risk calculations using CAROLA

This chapter contains a brief description of the procedure for performing a risk calculation using the CAROLA calculation package. Detailed information about the calculation package can be found in the user manual for the CAROLA calculation package [3].

4.1 Loading the background map

Load your own background map and calibrate the map using (x, y) coordinates in the Dutch National Triangulation System by specifying three points and their coordinates on the map. The program uses these coordinates to calibrate the map and check the calibration. If the internal calibration check shows that the calibration is incorrect, an error message is displayed and the calibration process will have to be repeated. The format for the permitted background maps is bmp, tif and jp(e)g. The program displays the background map with a suitable scale and north arrow. The background map is square; the maximum size of the map is limited to 40 × 40 km^2.

4.2 Selecting the area of interest

Select the area on the map that you are interested in (see section 3.4.3 also) by specifying a polygon (by clicking the map a number of times). The area of interest must fit within a square of 10 × 10 km^2 on the background map. The area of interest must be saved to a text file and sent to the pipeline operator(s).
Using the text file, the pipeline operator selects the relevant pipelines, together with the corresponding pipeline-specific parameters. The pipeline operator returns an encrypted file containing the information about the pipeline. These files contain all pipelines that are within a distance of at least 1 km + 2 times the maximum effect distance for the area of interest.

4.3 Loading the encrypted file containing pipeline details

Load the encrypted file(s) containing pipeline information into the calculation package. The position of the pipeline is automatically displayed in the area. Depending on the size of the background map, the pipeline could be drawn outside of the original background map.
The calculation package automatically performs a number of checks on the imported data:

- Calculations can only be performed on pipeline data that has been encrypted and supplied by the pipeline operators.
- The date of the pipeline data is checked: the encrypted pipeline file contains a pre-determined validity date to ensure that correct and up-to-date data is used in the calculations.
- The area of interest defined in section 4.2 is also included in the pipeline file and used by the calculation package. If files containing pipeline data are loaded, then the program checks if these polygons match the area of interest in the project file. If they do not, an error message is displayed and the calculation cannot continue.

- If the name of the pipeline operator, as stated in the encrypted file, does not match one of the pipeline operators already mentioned in the parameter file, the calculation package displays an error message and the calculation is not performed.
- Once the pipeline data has been loaded, the background map is reduced in size.

The calculation package displays a list of the imported pipelines. The pipelines can be queried by diameter, pressure and location-specific mitigation measures to be taken or that have been taken (if applicable) by selecting the pipeline with the mouse. This displays a pop-up window with the information requested. The pipeline data cannot be changed.

4.4 Calculating the individual risk

Calculate the individual risk (IR) for all individual pipelines. Then one of the pipelines concerned can be selected from the list of pipelines for which the IR is displayed. Here you can choose to display areas and/or contours. The 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} and 10^{-8} PR contours can be displayed per year (if they exist).

The IR contours for each individual pipeline can be exported to a GIS shapefile with polygon geometry.

When the calculations described in this paragraph are complete, it is possible to stop the calculations and go straight to a summary report (section 4.8). The societal risk results are then excluded from the summary report.

4.5 Displaying the area of influence

The calculation package displays the area of influence for the societal risk calculations for all of the pipelines involved. This makes the area that affects the societal risk the most, clear at a glance.

4.6 Entering population data

The population details within the area of influence can be imported in the following two ways:

- Previously created population text files. These can be imported by the user. The population file to be imported comprises separate lines, each line containing the x and y coordinates respectively and the number of people at this coordinate. The values are separated by a tab, space or comma. The 3 lines below contain an example of the layout of the file:
  144471, 455784, 2.35
  140183, 462238, 3.33
  140847, 457541, 2.10
- Clicking on the map. By clicking on the map, an area can be defined and the population in this area can be entered as a density or as actual numbers. There are two options here, replacing the existing, previously loaded population (including deleting the existing population that has been loaded from previously created text files) or adding to an existing population.

An unlimited number of population files can be imported or defined manually. There is no prescribed order for implementing these methods. However, each manually defined area and each text file contains one type of population (residents, workers or people present at events).

When loading a text file or defining an area on the map, the user is asked to select the type of population (residential, working or events). A summary of the basic principles for the population types in included in section 3.4.

4.7 Societal risk calculations

Calculate the societal risk (SR) with the corresponding FN curve. The societal risk is screened based on the factor for exceeding the orientation value ($F \cdot N^2 = 0.01$). The screening is done by calculating the factor for exceeding the orientation value for the SR per point on the pipeline (stationing), taking account of one kilometre of pipeline around that point (500 metres on either side). This screening results in a graph with the stationing on the horizontal axis and the exceedance factor on the vertical axis. The user can use this graph to immediately determine the 'worst case' kilometre for the SR. The map, the graph described above and the actual societal risk curve (FN curve) are interlinked.

Societal risk calculations are performed and displayed for 1 km of pipeline. This pipeline section is displayed on screen in green by default, as shown in Figure 2. The stationing is shown in ascending order, and is independent of the direction in which the pipeline is displayed on screen.

The FN curve can be exported, just like the screening and the background map (in the way it is displayed in the calculation package) with the marked kilometre that is shown on the screening and the map. In addition, it is also possible to save the corresponding (cumulative) FN points in a text file.

When a pipeline has a total length of less than 1 km the FN curve is calculated for the entire pipeline. The orientation value remains unchanged ($F \cdot N^2 = 0.01$).

By default, all FN curves are displayed with an X axis of N = 10 to 1000, or to 10,000 when there are more than 1000 victims; the Y axis with F varies from 10^{-3} to 10^{-9}.

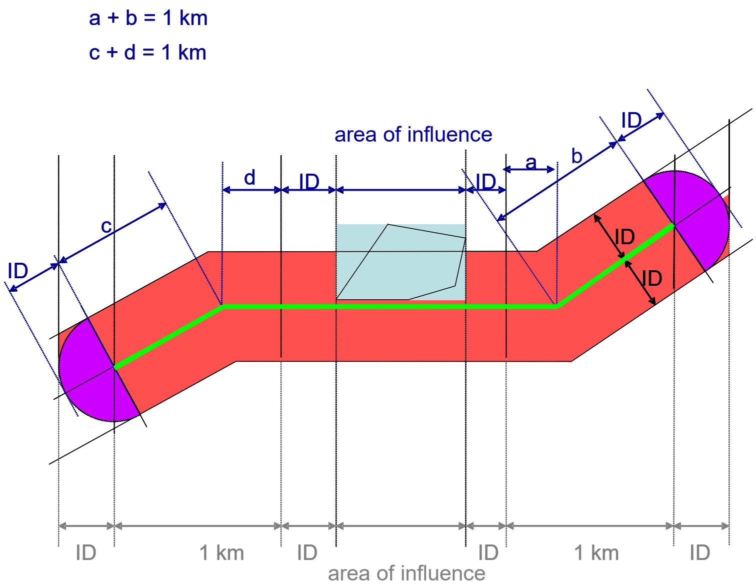

Figure 2 Part of the pipeline for which the societal risk can be calculated.

4.8 Summary report

After the calculations have been performed for the individual risk (and, if calculated, the societal risk) a short summary report can be generated. This contains the following components:

- The version number of the calculation package
- The version number of the parameter file
- The calculation date
- The date the pipeline data was created
- Legend
- Pipeline operator
- Name and date under which the project file that was used in the calculations was saved
- The pipelines, including name, diameter (inches), pressure (barg) and risk limiting measures taken into account in the risk calculation, an image of the PR contours and the image with the population data on the background map
- The graph with the screening of the societal risk (if applicable)
- The FN curve for the 'worst case' kilometre of the pipeline (i.e. the pipeline kilometre with the highest exceedance factor), together with a figure for this kilometre on the background map (if applicable)

The report is created in Word format. The report contains a minimal description of the technical section of the QRA report and does not meet the report obligations as described in section 5.2 and/or other conditions imposed by a client or competent authority.

5 Technical documentation

5.1 Introduction

The risk assessment must be documented in such a way that a competent authority has enough information to effectively evaluate the contents of the risk assessment. Deviations from the standard modelling are not possible in principle, as the entire calculation method is stipulated [4], [5]. This chapter describes what documentation needs to be available in order to assess a QRA and specifies the report obligation of a QRA in detail.

5.2 Report obligation of a QRA to a competent authority

Table 12 specifies the elements for an independent QRA, based on the output of the CAROLA calculation package as described in section 4.8.

Table 12 Overview of the items that need to be incorporated in a QRA.

	Subject	Confidential/ Public
1	**General report information**	
	Administrative information: • name and address of the pipeline operator(s) (according to Bevb) • name and address of the author of the QRA	Public
	Reason for performing a QRA	Public
	Method used • calculation package and version number • parameter file and version number	Public
	QRA set date • The calculation date • The date the pipeline data was created	Public
2	**General description of the pipeline(s)**	
	Pipeline details • name of the pipeline • description of the natural gas (dry/wet/acid, CGR and calorific value) • diameter • maximum operating pressure • any mitigating measures	Public
	Location of the pipeline, based on scaled map(s) • pipeline • north arrow and scale indication	Public
3	**Description of surrounding area**	
	Local development and designated purpose for the area • land-use plans whether or not partly within the PR 10^{-6} contour and the area of influence	Public
	Current topographic map	Public
	A description of the population around the pipeline, specifying the way in which this description has	Public

	Subject	Confiden-tial/ Public
	been made (among others: incidental constructional development, ribbon development)	
	Possible dangers from outside the pipeline which might affect the (failure frequency of the) pipeline (objects that increase the risk, neighbouring busi-nesses/activities, flight paths, wind turbines, trans-mission tower)	Public
	Weather station used	Public
4	**Description per pipeline of possible risks to the surrounding area**	
	Summarizing overview of the QRA results which includes at least the following:	Public
	Map with calculated individual risk, with contours for 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} and 10^{-8} (if present)	Public
	FN curve for both the current and future situation, with the societal risk for the pipeline kilometre with the highest exceedance of the orientation value. The horizontal axis of the graph with the FN curve sets out the number of fatalities, the vertical axis sets out the cumulative probability to 10^{-9} per year	Public
	FN data point at which the maximum exceedance of the orientation value occurs, including the exceed-ance factor	Public
	Graph with the screening of the societal risk	Public
	Description of the sensitive land-uses and/or mod-erately sensitive land-uses within the PR contour for 10^{-6} per year	Public
	Proposed preventative and repressive measures included in the QRA	Public

6 Explanatory notes for Module B

6.1 Model parameters (Chapter 2)

6.1.1 Mitigating measures for damage by third parties

The preconditions for the various measures are shown below.

Additional ground cover
A precondition for this measure is that the cover must be effective on both sides of the pipeline. The cover must be applied in such a way that it can be expected that an excavating contractor who digs perpendicular to the pipeline continues to follow ground level and does not ignore the additional cover by following the level at excavation depth. For additional ground cover up to 20 cm, the cover must be applied over a minimum of 10 metres on either side of the pipeline. For additional ground cover exceeding 20 centimetres, the additional cover must be applied over a minimum of the right of way.

Cluster 1
1A WIBON legislation
- The preconditions are given in WIBON [14].

1B Case studies
This factor is based on the case studies by N.V. Nederlandse Gasunie [4]. The preconditions for the implementation of this factor by other operators have yet to be established. The operator is allowed to make its own estimate whether this factor also applies in their case. The procedure for this is described in [16].

1C Active reminder
- The operator must contact the excavation contractor within 10 days of notification if they have not already done so.

Cluster 2
21 warning tape, 22 protection plates, 23 warning tape and protection plates.
- The minimum distance between a pipeline and the protection material and the width of the cover must be recorded in a standard document. The combination of both factors (protection material and the distance between the material and the pipeline) must be such that the cover is effective and there is no contact with the pipeline even when employing the largest excavators that are in use at that time.
- The strength and suitability of different materials and structures should be demonstrated by field testing. The basic principle is that field testing is carried out in the same way as the field testing that was carried out to determine the reduction factor for

protection plates [17]. The reduction factor can then be derived in the same way[3].
- If the cover on one pipeline also covers other pipelines, the other operators will have to be consulted in this case.
- This measure can only be implemented when the pipeline operator grants permission for taking these measures. It is primarily the effect of the cathodic protection and, for instance, the accessibility for coating inspections that are important in the considerations.

Cluster 3
31 Agreement, extensive restrictions
- The land is taken out of use by leasing the land or by a strict management agreement that excludes all use of the land.
- The relevant part of the land is fenced-off.
- Markers are applied.
- The landowner must be contacted periodically (at least once each year) to discuss the situation concerned.
- During the (helicopter) inspections, the pipeline section to which the agreement applies must be given specific attention.
- It must be possible to reject and never accept any request for excavation work by the owner and third parties. Immediate action is required upon receipt of a notification. It must be immediately clear to those handling the notification that a management agreement applies to the pipeline section concerned.
- If an agreement does not comply with all of the preconditions, the agreement will, at the very most, deliver the reduction factor for an agreement where digging/drilling is prohibited.

32 Agreement, digging/drilling prohibited
- An agreement that excludes excavation work, permits to use the land, for example, as pasture. Use as a parking or storage site, for instance, is also possible, if no excavation work is required to realise this.
- The landowner must be contacted periodically (at least once each year) to discuss the situation concerned.
- During the (helicopter) inspections the pipeline section to which the agreement applies must be given specific attention.
- It must be possible to reject and never accept any requests for excavation work by third parties. Immediate action is required upon receipt of a notification of excavation work. It must be immediately clear to those handling the notification that a management agreement applies to the pipeline section concerned.
- If an agreement does not comply with all of the preconditions the agreement will, at the very most, deliver the reduction factor for an agreement with limited restrictions.

[3] If the measure proves to be effective in all experiments then when deriving the reduction factor it must be assumed that the measure was not effective for one experiment. This assumption is necessary because with a limited number of tests (n) it is not possible to rule out the $(n+1)^{th}$ test resulting in failure.

33 Agreement, limited restrictions
- In an agreement with limited restrictions, excavation work is not completely excluded but is limited by the depth of the excavation.
- The landowner must be contacted periodically (at least once each year) to discuss the situation concerned.
- During the (helicopter) inspections, the pipeline section to which the agreement applies must be given specific attention.

Cluster 4
41 Fencing
- A fence must prevent entry into the immediate vicinity of the pipeline. If fencing only encloses the area near to the pipeline but the area can easily be entered otherwise, fencing must be consider to be marking.
- This measure must be used in combination with marking.
- Accessibility of the pipeline must not be hindered.

42 Embankment
- The embankment in relation to ground level is at least one metre high and this height must be maintained. Another option is to create an embankment 50 cm high but in this case the embankment must be enclosed by a (metal) net that can provide sufficient resistance if excavation work will take place.
- The embankment must be continuous over the pipeline section for which the measure is applied. Because it is not possible to avoid crossing roads etc. the guideline is that at least 98% of the pipeline section concerned must be protected by an embankment. If less than 98% of the pipeline section is protected, a QRA must take specific account of the interruptions. The section that is not protected by an embankment must be protected in another way, by road paving for instance. In addition, additional marking must be placed at the start and end of the interruption.
- The measure must be used in combination with marking.
- The embankment must not have any impact on the integrity of the pipeline.
- This measure must be used in combination with marking.
- Accessibility of the pipeline must not be hindered.

43 Ground-level barrier
- The distance between the barrier and the pipeline must be limited to one to two metres from the pipeline.
- Free-standing poles must be positioned maximally 20 cm apart.
- This measure must be used in combination with marking.
- Accessibility of the pipeline must not be hindered.

Cluster 5
51 Strict supervision of activities
- In the event of a notification the pipeline operator must make immediate contact with the contractor performing the activities. During this contact, working agreements that are made should be recorded in writing. The pipeline operator must check the situation *in situ* daily, until contact is established with the contractor.

- If there is more than one week between the notification and the start of the activities, the pipeline operator must contact the contractor performing the activities every week (until the start of the activities).
- If the activities last longer than one week the pipeline operator must carry out an additional *in situ* inspection every week (until the activities have been completed).
- Additional marking is to be used during the activities.
- It must be immediately clear to the pipeline operator's staff handling the notification that strict supervision applies to the pipeline section concerned. This is to be guaranteed in the procedure for dealing with the notifications.

52 Camera monitoring

- Monitoring must be continuous.
- It must be possible to monitor the entire pipeline section for which the reduction factor is used.
- When detecting (preparations of) activities in the proximity of the pipeline, it must be possible to intervene within minutes to stop these activities.
- Notified activities must be reported to the individual doing the monitoring to prevent false alarms.

6.1.1.1 Cluster 1 - regulations and case studies

In line with the procedure agreement proposed by VROM [16], a number of operators take the factor for active reminder (Cluster 1C) into account in the calculations. These factors are applied in the consequence analysis [17] and adopted in the CAROLA calculation package. A consequence analysis has not been carried out for the pipelines of Alliander, RWE Westfalen-Weser-Ems Netzservice GmbH and Tulip Oil Netherlands BV. In this case no implementation is assumed for the active reminder.

6.1.2 Mitigating measures for corrosion

In line with the procedure agreement proposed by VROM [16], a number of operators take the factor for mitigating measures for corrosion into account in the calculations. These factors are applied in the consequence analysis [17] and adopted in the CAROLA calculation package. A consequence analysis has not been carried out for the pipelines of Alliander, RWE Westfalen-Weser-Ems Netzservice GmbH and Tulip Oil Netherlands BV. It is assumed that no additional measures for corrosion are applied here.

6.2 Technical limits for input data in CAROLA

Outside diameter

The outside diameter must be denoted in mm. All values between 50 mm and 1234 mm are permitted (a 2 inch and 48 inch gas pipeline have a diameter of 60.3 mm and 1219 mm respectively). The origin of these limits is explained below. Whenever 'diameter' is mentioned it refers to the outside diameter.

Yield stress

The yield stress must be specified in N/mm^2 and values between 180 N/mm^2 and 552 N/mm^2 are permitted. The usual lower limit for the yield stress that equates to Grade B is 241 N/mm^2, but a lower limit can be entered down to 180 N/mm^2. The upper limit equates to X80 pipelines with a yield stress of 552 N/mm^2.

Wall thickness
The wall thickness must be entered in mm. Any value between 2 mm and 40 mm is permitted.

Pressure
The pressure is denoted in bar (g). All values between 16 bar and 300 bar are permitted. Whenever 'bar' is mentioned it refers to bar (g).

Charpy energy
The Charpy energy is entered in J. All values between 13 J and 1000 J can be entered. The selection of the values used in the calculations takes place in accordance with Table 15.

Construction factor
The construction factor, as defined below, is not input data but is used to check whether the combination of diameter, pressure, wall thickness and yield stress is valid. The construction factor must lie between 0.025 and 0.75. The construction factor is defined as:

$$\frac{P(D-d)}{20d} = CF \cdot YS, \qquad WT = \begin{cases} d + 0{,}35 & if \quad d < 10 \\ d + 0{,}5 & if \quad d \geq 10 \end{cases} \qquad (10)$$

with the pressure P in bar, the diameter D in mm, the wall thickness WT in mm, the wall thickness used in the calculations *d* in mm, the yield stress YS in N/mm^2 and the construction factor CF (dimensionless).

Depth
The depth must be denoted in m. Although there is no strict upper limit of depth, it must range from 0 m to 30 m. This upper limit is used to locate errors in the unit for depth: the depth is not accepted when it is denoted in cm.

Discrete values
Tables for the thermal radiation, the failure frequency due to damage by third parties and the corrosion failure frequency have been generated for CAROLA. This requires discrete values for diameter, pressure, wall thickness, yield stress and Charpy energy, for which thermal radiation and failure frequencies have been calculated. However, when applying a simple approach, this results in tables for failure frequencies with many pointless values, such as a 1219 mm pipeline, 150 bar, Grade B, 2 mm wall thickness. This is problematic because the tables become very large (for instance, for 4 parameters with 20 discrete values each table already has 160,000 cells). The CAROLA library uses therefore internally not the wall thickness as a parameter, but the construction factor.

Diameter
The values as included in Table 13 are used for the diameter. The diameters are also shown in inches and DN.

Table 13 Diameters used in CAROLA.

Diameter (inches)	Diameter (DN)	Diameter (mm)
<lower limit>		50
2	DN50	60.3
3	DN75	88.9
4	DN100	114.3
6	DN150	168.3
8	DN200	219.1
10	DN250	273.1
12	DN300	323.9
14	DN350	355.6
16	DN400	406.4
18	DN450	457
20	DN500	508
22	DN550	559
24	DN600	610
26	DN650	660
28	DN700	711
30	DN750	762
36	DN900	914
42	DN1050	1067
48	DN1200	1219
<upper limit>		1234

Yield stress
The values from Table 14 are used for the yield stress. The corresponding steel type has been added for informative purposes.

Table 14 Values for yield stress in CAROLA.

Steel type	Yield stress (N/mm^2)
Lower limit	180
Grade B	241
X42	290
X46	317
X52	359
X56	386
X60	414
X65	448
X70	483
X80	552

Construction factor
The following (62) values are used for the construction factor: 0.025, 0.05, 0.1, 0.15, 0.16, ..., 0.71, 0.72, 0.75.

Pressure
The following (18) values are used for pressure: 16, 25, 32, 40, 48, 66.2, 73, 80, 90, 100, 110, 120, 130, 140, 150, 200, 250 and 300 bar.

Charpy energy
The values 14, 24, 40 and 70 J are used for the total Charpy energy. CAROLA uses the limits as shown in Table 15.

Table 15 Limits for Charpy energy values.

Charpy lower limit (J)	Charpy upper limit (J)	Selected Charpy (J)
13	23	14
23	39	24
39	69	40[4]
69	1000	70

Wind speeds
The default values of 1.5, 3, 5 and 9 m/s are used.

Wind directions
12 Wind directions are used (N, NNE, ENE, E, ESE, SSE, S, SSW, WSW, W, WNW, NNW).

Ignition
The values for 0 s and 120 s are used.

Position on radial directions
28 distances are used for the radial distances in the thermal radiation tables: 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100, 120, 140, 160, 180, 200, 250, 300, 350, 400, 450, 500, 600, 700, 800, 900 and 1000 m.

Tables
Thermal radiation
To specify the thermal radiation, 5-D-tables are used for diameter / pressure / wind speed / wind direction / position on radial direction / and combinations for delayed ignition where, as specified, the discrete values for the diameter and the pressure are used. Depth and wall thickness have an effect on the thermal radiation (because they affect the dimensions of the crater and the internal diameter) but these parameters have default values as specified in Table 16.

Table 16 Default depth for thermal radiation.

Diameter (mm)	Depth (m)
60.3 - 406.4	1.2
457 - 1219	1.75

The wall thickness (which is required because the outflow depends on the internal diameter) is calculated from the diameter (D) and pressure (P), using

[4] In fact, 40.5 J is used for historical reasons.

$$WT = \frac{P \cdot D}{20 \cdot 0{,}65 \cdot YS + P}, \qquad YS = \begin{cases} 240 & if \quad D < 300 \\ 415 & if \quad 300 \leq D \leq 700 \\ 480 & if \quad D > 700 \end{cases} \tag{11}$$

The thermal radiation is given for the four wind speeds (1.5, 3, 5 and 9 m/s) and for 7 radial directions (the other 5 directions can be obtained by mirroring). The thermal radiation is only calculated for the wind from the south on these 7 radial directions. The direction numbers 1 through 7 equate to N, NNE, ENE, E, ESE, SSE and S.

The size of the table becomes 19 (diameter) × 18 (pressure) × 4 (wind speed) × 7 (wind direction) × 28 (position on radial direction) × 2 (ignition time) = 536,256 cells.

Failure frequency for damage by third parties
The failure frequency due to damage by third parties is given as a 5-D table depending on the diameter, pressure, construction factor, yield stress and Charpy energy. The frequency also depends on the depth, but the table is generated for a reference depth of 1.31 m.

The size of the table is 21 × 18 × 62 × 10 × 4 = 937,440 cells.

The correction in the failure frequency (C_{ff}) for the actual depth is in accordance with [5], where

$$C_{ff} = e^{2{,}4 \cdot z_0 - 2{,}4 \cdot z} \tag{12}$$

where
z_0 = reference depth (m)
z = actual depth (m)

Corrosion failure frequency
The corrosion failure frequency is denoted as a 4-D table depending on the diameter, pressure, construction factor and yield stress.

The size of the table is 21 × 18 × 62 × 10 = 234,360 cells.

Probability of ignition
The probability of ignition (*IP*) is available as a function. This function depends on the diameter (*D*) and the pressure (*P*)

$$IP = \begin{cases} f(P,D) + 0{,}1 & if \quad D < 410 \\ f(P,D) & \text{otherwise} \end{cases} \tag{13}$$

where *f* is the PIPESAFE formula for ignition probability [5].

Interpolation and extrapolation
In general there is no extrapolation outside of the specified margins. There is no interpolation for the wind speed, Charpy energy and delayed ignition.

Thermal radiation
For thermal radiation, there is no interpolation of the diameter. Instead this is chosen using Table 17. 5 mm is approximately 10% of 2 inches,

15 mm is approximately 10% of 6 inches. This is why the rounding is usually conservative.

Table 17 Diameter used by CAROLA with upper and lower limits.

Lower diameter (mm)	Upper diameter (mm)	Diameter (mm)	Diameter (")
50 (selected manually)	65 (= diam +5)	60.3	2
65	94 (= diam +5)	88.9	3
94	119 (= diam +5)	114.3	4
119	173 (= diam +5)	168.3	6
173	224 (= diam +5)	219.1	8
224	278 (= diam +5)	273.1	10
278	329 (= diam +5)	323.9	12
329	361 (= diam +5)	355.6	14
361	411 (= diam +5)	406.4	16
411	462 (= diam +5)	457	18
462	513 (= diam +5)	508	20
513	564 (= diam +5)	559	22
564	615 (= diam +5)	610	24
615	665 (= diam +5)	660	26
665	716 (= diam +5)	711	28
716	777 (= diam +15)	762	30
777	929 (= diam +15)	914	36
929	1082 (= diam +15)	1067	42
1082	1234 (= diam +15)	1219	48

The thermal radiation for a specific pressure is obtained by linear interpolation of two pressures for which the radiation is given, in other words, when the thermal radiation at 50 bar is required interpolation between 40 and 66.2 bar is used. The interpolation of the pressure is part of the CAROLA library.

The calculation package rotates the thermal radiation for wind directions other than from the south.

How to obtain the thermal radiation at the 28 positions of the 12 radial directions for a specific diameter, pressure, wind speed and ignition is described above. Calculating the thermal radiation at a specific coordinate (interpolation between the 12 radial directions and 28 positions on the radial directions) is done by the calculation package.

Failure frequencies
The correct frequency for a specific diameter, pressure, construction factor and the yield stress must be obtained by interpolation. This interpolation is part of CAROLA's library. It is done by first finding the two values for the diameter, pressure, construction factor and two values for the yield stress to be used in the interpolation. Then a logarithmic interpolation is performed for the yield stress, wall thickness, and pressure and finally a bilogarithmic interpolation is performed for the diameter.

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Module C - Pipelines for petroleum products and flammable liquids

Version 3.2
01 January 2021

Introduction

This module describes how a QRA should be carried out for underground pipelines carrying petroleum products and flammable liquids that are part of the Bevb. The basic principles for calculations using the Safeti-NL calculation package [1] are described in this module. To avoid confusion the above-mentioned pipelines are designated as 'pipelines carrying petroleum products' in this module. After all, not all flammable liquids are included in Module C as some flammable liquids are included in Module D (chemical pipelines, see section 8.1) based on the flash point and boiling point.

The substantiation for the risk assessment method for underground transport pipelines carrying petroleum products is described in a RIVM report [2]. This concerns the substantiation for the scenarios, failure frequencies, source terms and the effects that are included. This report can be accessed via the RIVM website.

8 Calculation method

8.1 Pipeline types

The Safeti-NL calculation package can be used to perform calculations for pipelines carrying various types of petroleum products. The method as described in this module can only be used for performing risk calculations for underground transport pipelines carrying petroleum products. Petroleum products include: petroleum, petroleum gas, liquid petroleum products and derivatives, insofar the flammable liquid does not contain components in quantities that can lead to toxic or explosive effects.

In this calculation method petroleum products are subdivided into three categories based on their flash point:

- Category I - Petroleum products with a flash point up to 294 K (21 °C). Exceptions are flammable liquids with a boiling point not exceeding 308 K (35 °C) and a flash point lower than 273 K (0 °C).
- Category II - Petroleum products where the flammable liquid has a flash-point equal to or higher than 294 K (21 °C) and not exceeding 328 K (55 °C).
- Category III - Petroleum products where the flammable liquid has a flash-point higher than 328 K (55°C) and not exceeding 373 K (100 °C).

Flammable liquids with a boiling point not exceeding 308 K (35 °C) and a flash point lower than 273 K (0 °C) are covered by Module D.

9 Model parameters

9.1 Introduction

In a risk calculation using the Safeti-NL QRA calculation package, a number of choices has to be made and a large number of parameter settings entered. This chapter describes a number of choices in the modelling process and the parameters relevant to the risk calculations. Two types of parameters are distinguished:

- Parameters the user can modify to align the calculation with the pipeline-specific and location-specific conditions. These are the QRA-specific parameters and they are set out in section 9.2.
- Parameters the user cannot modify, but that are characteristic of a QRA calculation in the Netherlands. These are set out in section 9.3.

There are other parameters that cannot be modified by the user, but are part of the model, and parameters that do not affect the calculation results, but only determine the presentation of (intermediate) results. These parameters are set out in the documentation for the calculation package.

9.2 QRA-specific parameters

The parameters in this category can be modified to align the calculation with the specific conditions of the underground pipeline.

9.2.1 Position of the outflow

Each scenario includes an outflow position, which is determined by the location (x, y) in relation to the surrounding area. The length of the pipeline is also relevant for the outflow rate.
The 'route model' is used to obtain a representative risk contour for long transport pipelines. The spacing of events is chosen so small that a representative risk contour is generated.

9.2.2 Outflow scenarios

Two types of outflow scenario are distinguished for underground pipelines carrying liquid petroleum products: (1) rupture of a pipeline and (2) leak from a pipeline.

9.2.2.1 Rupture

In the case of a rupture, the outflow will be directed towards ground level. It is assumed that the released liquid emerges aboveground and spreads there. The following contribute to the outflow emerging aboveground:

1. The liquid that is released within the shut-down time of the pump.
   This amount is calculated by multiplying the pump shut-down time by the pump flow rate. The pump shut-down time should be determined for each pipeline individually. The stipulations described in section 9.3.1. have to be taken into account.
2. Outflow resulting from expansion of the compressed liquid.
   The compressed liquid will expand as a result of a decrease in

pipeline pressure. The increase in volume is calculated using the following formula:

$$V_e = {}^{\pi}/_{4} \times D^2 \times L \times P \times C_e \qquad (14)$$

where:

V_e	increase in the volume of the product	(m^3)
D	internal diameter of the pipeline	(m)
L	length of pipeline between pumps or pump and the end of the pipeline	(m)
P	operating pressure at the rupture site	(Pa)
C_e	compressibility of the product	(m^2/N)

When a pipeline is filled and pumping is not taking place, outflow in the event of pipeline rupture will only result from expansion of the compressed liquid (V_e).

It is recommended that the subsequent outflow as a result of an inclining pipeline and additional outflow resulting from backflow from the receiving storage tanks, is taken into account.

9.2.2.2 Leakage

Leaks will not make any substantial contribution to the risk. They only lead to the soil saturation of the liquid. A leak is modelled as an outflow from a hole with an effective diameter of 10% of the nominal diameter of the pipeline, with a maximum of 20 mm. A leak results in a much lower outflow rate than a rupture. As a result, the 'leak' scenario has no significant effect on the location-specific risk contours. This does not apply for toxic liquids or liquids containing toxic products.

9.2.3 Failure frequencies

The failure frequencies for a pipeline apply to the pipeline including flanges, welds and valves but excluding pumps. The scenarios and frequencies for underground petroleum product pipelines are shown in Table 18. The distribution of causes of failure is shown in Table 19 [3].

Table 18 Scenario for pipelines carrying petroleum products.

Scenario	**Failure frequency (km^{-1} $year^{-1}$)**
Rupture in the pipeline	1.5×10^{-4}

Table 19 Cause of failure distribution for the rupture scenario for pipelines carrying petroleum products.

Cause of failure	**Failure frequency**	**Proportion (%)**
Damage by third parties	7.19×10^{-5}	47.9
Mechanical	3.23×10^{-5}	21.5
Internal corrosion	5.71×10^{-6}	3.8
External corrosion	1.72×10^{-5}	11.5
Natural causes	9.15×10^{-6}	6.1
Operational/other	1.38×10^{-5}	9.2
Total	$\mathbf{1.50 \times 10^{-4}}$	**100**

Notes:

- The rupture frequency is determined generically for all relevant pipelines carrying petroleum products in the Netherlands.
- The effect of the Excavation Contractors Regulation (Underground Grids (Information Exchange) Act or WION), is taken into account in the failure frequency by reducing the number of ruptures as a result of damage caused by third parties (external interference) by a factor of 2.5 [4].
- The depth is taken into account in the 'Damage by third parties' cause of failure [3, 5]. The adjusted failure frequency is:

$$\text{failure frequency}_{\text{damage by third parties, adjusted}} = \text{failure frequency}_{\text{damage by third parties}} / \text{factor} \quad (15)$$

where:

$$\text{factor} = e^{-2.4 \times (0.84 - z)} \quad (16)$$

and:
z = depth (m).

Transitions in depth of 20 cm or more should be included in the calculations. In addition, depth transitions of 10 cm or more that continue over a pipeline distance of 50 metres or more should be included. One may devi-ate from these requirements if a conservatively chosen pipeline depth did not generate any bottlenecks or problems. This could be the case for pipelines in rural areas. Accurate calculations are only necessary here when problems could arise, for example through changes in land use planning in which a (moderately) sensitive object is permitted near the pipeline.

9.2.4 *Modelling scenarios*

A Pool fire model should be used to calculate the risks and effects. The volume of the pool is determined based on the considerations mentioned in section 9.2.2.
A default value of 0.05 metres is used for the pool depth of an outflow. This can be modelled by selecting a Pool fire with a diameter in accordance with the formula:

$$d = 2 \times \sqrt{\frac{V}{\pi \times h}} \quad (17)$$

where:

d	diameter of the pool	(m)
V	total outflow volume of the product	(m^3)
h	pool depth, default 0.05 metres	(m)

The probability of immediate and delayed ignition depends on the substance category. The values for underground transport pipelines are given in Table 20.

Table 20 Probabilities of ignition.

Liquid category	P_{total}	$P_{immediate}$	$P_{delayed}$
I	1	0.065	0.935
II	0.01	0.01	0
III	0.01	0.01	0

Notes:
- To determine the frequency used in a Pool fire, the frequency from Table 18 (or Table 10) has to be multiplied by the appropriate probability of ignition in Table 3.
- For categories II and III, the combination of the frequency from Table 18 (or Table 10) and the ignition probability from Table 3 does not result in a PR 10^{-6} risk contour or a relevant group risk. A QRA is therefore not required for these pipelines.
- For flammable/combustible liquids, no site boundary needs to be specified in Safeti-NL as the instantaneous ignition probability is equal to 1.

9.2.5 *Pressure loss as a result of valves and bends*
Pressure loss in a pipeline due to the presence of valves, joints and bends is by default not taken into account in the calculation.

9.2.6 *Roughness length of the surrounding area*
The roughness length is an (artificial) length measurement that indicates the impact of the surrounding area on wind speed. The default roughness length of the surrounding area to determine the wind profile is 0.1 metres. The description of the surrounding area is included in Table 21.

Table 21 Description of terrain type with roughness length.

Description of surrounding area	Roughness length
Open water, at least 5 km	0.0002 m
Mud flats, snow; no vegetation, no obstacles	0.005 m
Open, flat terrain; grass, a few isolated objects	0.03 m
Low vegetation; large obstacles here and there, x/h > 20	0.10 m
High vegetation; distributed large obstacles, 15 < x/h < 20	0.25 m
Park, bushes; many obstacles, x/h < 15	0.5 m
Covered with large obstacles (suburb, forest)	1.0 m
Town centre with high-rise and low-rise buildings	3.0 m

Notes:
- *x* is a typical distance between obstacles upwind and h is the typical height of the obstacles.
- Roughness lengths of one metre and greater are rough estimates; the aerodynamic roughness length does not take dispersion around large obstacles into account.
- A typical roughness length for an industrial area is one metre.

9.2.7 *Weather station and parameters*

The weather station representative for the location of the pipeline must be selected. The user has a choice of weather stations as specified in Table 22.

Table 22 Weather stations.

Name				
Beek	Eindhoven	Leeuwarden	Twente	Woensdrecht
Deelen	Gilze-Rijen	Rotterdam	Valkenburg	Ypenburg
Den Helder	Hoek van Holland	Schiphol	Vlissingen	
Eelde	IJmuiden	Soesterberg	Volkel	

Default values for a number of meteorological parameters are shown in Table 23. The values are yearly averages.

Table 23 Default values for a number of meteorological parameters.

Parameter	**Day default value**	**Night default value**
Ambient temperature	12 °C	8 °C
Temperature at soil surface	9.8 °C	9.8 °C
Water temperature	9.8 °C	9.8 °C
Atmospheric pressure	101550 N/m^2	101550 N/m^2
Relative humidity	76.5%	86.3%
Global radiation	0.25 kW/m^2	0 kW/m^2
Fraction of a 24-hour period	0.44 (08:00 – 18:30)	0.56 (18:30 – 08:00)
Mixing height	See note	

Note:
- The default values for the mixing height are included in the model. They are 1500 metres for weather category B3, 500 metres for weather categories D1.5, D5 and D9, 230 metres for weather category E5 and 50 metres for weather category F1.5.

9.2.8 *Distribution inside and outside*

The population distribution between inside and outside is set out in Table 24. These values apply to residential and industrial areas, unless other information is available. For recreational areas, the type of recreational activity determines the population distribution between inside and outside.

Table 24 Distribution of population inside and outside throughout the day and night.

	Inside	**Outside**
Day	0.93	0.07
Night	0.99	0.01

Note:
- See the Societal Risk Accountability Guidelines [6] for more information.

9.2.9 *Modelling people at events*

People who are present only part of the year (or of the daytime period), such as in recreational areas or at events, must be included in the calculation if the contribution to the societal risk is relevant. The inclusion of such groups is done in Safeti-NL by defining different rows for time periods with a different number of people present, taking the required accuracy into account.

9.2.9.1 Obtaining realistic contours

The combination of a long pipeline with relatively small consequence areas may cause a problem in the calculation of the risk contour. NB: The maximum number of events that can be calculated on a route is 5000.

9.3 Parameters specific to a QRA in the Netherlands

The parameters in this category cannot be modified.

9.3.1 *Maximum outflow time and exposure time*

The maximum outflow time for performing risk calculations is 1800 seconds. This also applies to the maximum duration for the pool evaporation. It is assumed that intervention has been successful after 1800 seconds.
The maximum exposure time for thermal radiation is 20 seconds. The possibility of evacuation is not included in the QRA.

9.3.2 *Height for calculating the effects*

The thermal radiation dose is calculated at a height of one metre.

9.3.3 *Lethality - Probits*

The probability of dying, P_{lethal}, is calculated using the following probit:

$$P_{lethal} = 0{,}5 \times \left[1 + erf\left(\frac{\mathrm{Pr} - 5}{\sqrt{2}}\right)\right] \quad (18)$$

where

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \quad (19)$$

The probability of dying, P_{lethal}, for exposure to heat radiation (pool fire, jet fire) is given by the probit relationship:

$$\mathrm{Pr} = -36{,}38 + 2{,}56 \ln\left(\int Q^{4/3}\, dt\right) \quad (20)$$

where

Pr	probit associated with the probability of dying	(-)
Q	thermal radiation at time	t(W m^{-2})
t	exposure time	(s)

The calculation of the lethality for the location-specific risk and the societal risk is set out in Table 25. A dose is defined as a function of exposure time t and intensity I, namely $t \cdot I^{4/3}$ with the unit s-(W/m^2)$^{4/3}$. The dose value $2.29 \cdot 10^7$ s·(W/m^2)$^{4/3}$ corresponds to an exposure time t = 20 s and an intensity I = 35 kW/m^2. The minimum value of P_{lethal} that is still included in the calculation is 0.01.

Table 25 Probability of dying for flammable substances.

Area	Location-specific Risk	Societal Risk Inside	Societal Risk Outside
Flame zone	1	1	1
$t \cdot I^{4/3} \geq 2.29 \cdot 10^7$ $s \cdot (W/m^2)^{4/3}$	1	1	1
$t \cdot I^{4/3} < 2.29 \cdot 10^7$ $s \cdot (W/m^2)^{4/3}$	P_{lethal}	0	$0.14 \times P_{lethal}$

Note:
- The maximum exposure time to thermal radiation is 20 seconds.

9.3.4 *Representative substances*

When the liquid petroleum product that is being transported is a combination of several substances, a representative substance can be used in the risk calculations. Table 26 shows for every liquid category which representative and example substance should be used. The flash point of the representative substances is in the centre of the flash point zone for the liquid categories concerned.

Table 26 Choice of representative substances for liquid petroleum products.

Liquid category	Flash-point (°C)	Representative substance	Example substance	Density of example substance (kg/m³)	Flash point of example substance (°C)
I	0–21	Petrol	n-octane	703	12
II	21–55	Kerosene	n-nonane	718	31
III	> 55	Diesel oil			

Note:
- Since the ignition probabilities for categories II and III are identical, they have been combined. As a result of this, the calculated risks for Category III are conservative.

9.3.5 *Wind turbine influence*

The effect of wind turbines must be included in the risk determination. A method for determining the effect of wind turbines is given in [7].

10 Measures

10.1 Introduction

Mitigating measures provide the opportunity to reduce the risks of a pipeline. The additional mitigating measures set out in this chapter apply to all under-ground pipelines carrying petroleum products. Exceptions are[5]:

- Aboveground pipelines.
- 'Hot Lines' with an operating temperature above 100 °C. This includes pipelines carrying heavy 'crude oil' products such as wax, lubricants and bitumen which are heated and transported in heavily insulated pipelines or where the pipeline system has external heat sources to reduce the viscosity of the product or where, as a result of exploration, the extracted products are at a temperature above 100 °C.
- Plastic pipelines.

In order to apply a reduction factor, a number of preconditions must be met, which are described in the appendix.

The definition of the factors and preconditions are based, in part, on practical policy decisions. The policy-led justification of the derived factors and pre-conditions is set out in [3].

The measures described in this chapter limit the probability of failure. Measures that limit the effects are not mentioned but should be taken into account in the calculation method. This concerns particularly measures that detect pipeline failure and intervene, resulting in a reduction of the outflow duration (pressure relief devices for example).

10.2 Pipelines that comply with state-of-the-art conditions

The failure frequency and cause-of-failure distribution in Table 27 may be used for pipelines that comply with the state-of-the art conditions (see Table 30). When a specific cause of failure has not been investigated in detail or when one of the associated conditions has not been met, the failure frequency mentioned in Table 19 should be used for this cause of failure[6].

[5] The failure frequencies included in this module do not apply to these pipelines either.

[6] To calculate the external safety risks, the aforementioned cause of failure distribution (or the one mentioned in Table 2) does not need to be applied in the following situations:

- QRAs for petroleum pipelines that were drawn up prior to the announcement of the Calculation Method Reference Manual version 2.0 and where there is no (longer a) question of LSR problems and/or SR points for attention.
- QRAs that have been appropriately included in established land-use plans (no LSR problems/SR points for attention).

Table 27 Failure frequency and cause-of-failure distribution for the rupture scenario for pipelines carrying petroleum products that comply with state-of-the-art conditions.

Cause of failure	Failure frequency (km^{-1} $year^{-1}$)	Proportion (%)
Damage by third parties	17.7×10^{-6}	47.9
Mechanical	7.96×10^{-6}	21.5
Internal corrosion	1.41×10^{-6}	3.8
External corrosion	4.25×10^{-6}	11.5
Natural causes	2.26×10^{-6}	6.1
Operational/other	3.40×10^{-6}	9.2
Total	$\mathbf{3.70 \times 10^{-5}}$	**100**

Note:
- The depth is taken into account in the 'Damage by third parties' cause of failure. The way this should be done is described in section 9.2.3.

10.3 Mitigating measures for preventing damage by third parties

The failure frequency in relation to preventing damage by third parties can be adjusted using the following formula:

$$\text{failure frequency}_{\text{damage by third parties, adjusted}} = \text{failure frequency}_{\text{damage by third parties}} / \text{factor} \quad (21)$$

where:

$$\text{factor} = \text{factor}_{\text{cluster 1}} \times \text{factor}_{\text{cluster 2}} \times \text{factor}_{\text{cluster 3}} \times \text{factor}_{\text{cluster 4}} \times \text{factor}_{\text{cluster 5}} \times \text{factor}_{\text{cluster 6}} \times \text{factor}_{\text{cluster 7}} \quad (22)$$

For cluster 2 to 5, only one measure can be selected per cluster. This is due to potential mutual dependency[7].

10.3.1 Cluster 1 - Active reminder

No measure from cluster 1 or pipeline that complies with state-of-the-art conditions (see section 10.2).	factor: 1
Active reminder	factor: 1.2

10.3.2 Cluster 2 - Cover using protection material

This relates to measures where underground cover has been applied to the pipeline that is to be protected.

No measure from cluster 2	factor: 1
Warning tape	factor: 1.67
Protection plates	factor: 5
Warning tape + protection plates	factor: 30

[7] In this way, for instance, the *'extensive restrictions'* measure can also include the prohibition of digging and drilling. The permitted factor is then 100 and not 100 x 10 = 1000.

10.3.3 *Cluster 3 - Management measures*

Management measures relate to the limitation or exclusion of excavation work using a management agreement with the landowner. The management agreement contains one of the following restrictions:

No measure from cluster 3	factor: 1
Extensive restrictions	factor: 100
Digging/drilling prohibited	factor: 10
Limited restrictions	factor: 1.6

10.3.4 *Cluster 4 - Physical barriers at ground level*

These measures are intended to make clear that, should excavation work take place, these activities are not allowed to be carried out.

No measure from cluster 4	factor: 1
Fencing	factor: ∞
Embankment	factor: 10
Barrier at ground level.	factor: 8

10.3.5 *Cluster 5 - Other measures*

The measures in cluster 5 depend on cluster 1, only one measure can be selected.

No measure from cluster 5	factor: 1
No measure from cluster 1:	
Strict supervision of activities	factor: 3
Camera monitoring	factor: 2.6
Active reminder from cluster 1:	
Strict supervision of activities	factor: 2.5
Camera monitoring	factor: 2.4

For pipelines that comply with the state-of-the-art conditions, the factors of cluster 5 must be based on the factors stated in ‘Active reminder from cluster 1’.

10.3.6 *Cluster 6 - Additional ground cover*

Table 28 provides an overview of the reduction factor per 10 cm additional ground cover:

Table 28 Effect of increasing ground cover.

Additional ground cover (m)	**Reduction factor**
0.1	1.3
0.2	1.6
0.3	2.1
0.4	2.6
0.5	3.3
0.6	4.2
0.7	5.4
0.8	6.8

Additional ground cover (m)	Reduction factor
0.9	8.7
1.0	11.0

10.3.7 Cluster 7 - Wall thickness

Wall thickness excluding corrosion allowance is at least 15 mm	factor 10

10.4 Mitigating measures for the other causes of failure

For the other causes of failure only one measure can be applied per cause of failure, even if there are multiple measures that affect the same cause of failure.

10.4.1 Mitigating measures to prevent mechanical failure

The measures set out in this paragraph affect the 'mechanical failure' cause of failure. The failure frequency for mechanical failure can be adjusted using the following formula:

$$\text{failure frequency}_{\text{mechanical failure, adjusted}} = \text{failure frequency}_{\text{mechanical failure}} / \text{factor} \quad (23)$$

Only one measure can be applied.

Reducing the maximum permitted operational pressure to a level where the operational stress falls below 30% SMYS (Specified Minimum Yield Stress).	factor 10
Carrying out a suitable high-resolution metal loss In-Line Inspection (ILI) combined with proper defect analysis and repair if necessary.	factor 10

10.4.2 Mitigating measures for preventing internal corrosion

The measures in this paragraph affect the 'internal corrosion' cause of failure. The failure frequency for internal corrosion can be adjusted using the following formula:

$$\text{failure frequency}_{\text{internal corrosion, adjusted}} = \text{failure frequency}_{\text{internal corrosion}} / \text{factor} \quad (24)$$

Only one measure can be applied.

The transported medium is non-corrosive in relation to the pipeline material (and vice versa).	factor ∞
The medium to be transported has been made sufficiently non-corrosive in relation to the pipeline material but preventative measures and monitoring/protection devices are necessary. These could possibly fail.	factor 10
Carrying out a suitable high-resolution metal loss In-Line Inspection (ILI) combined with proper defect analysis and repair if necessary.	factor 10

10.4.3 *Mitigating measures for preventing external corrosion*

The measures in this paragraph have an effect on the 'external corrosion' cause of failure. The failure frequency for external corrosion can be adjusted using the following formula:

$$\text{failure frequency}_{\text{external corrosion, adjusted}} = \text{failure frequency}_{\text{external corrosion}} / \text{factor} \quad (25)$$

Only one measure can be applied.

The pipeline material is non-corrosive in relation to the environment.	factor ∞
Carrying out a suitable high-resolution metal loss In-Line Inspection (ILI) combined with proper defect analysis and repair if necessary.	factor 10

10.4.4 *Mitigating measures for natural causes*

The measures in this paragraph have an effect on the 'natural causes' cause of failure. The failure frequency for natural causes can be adjusted using the following formula:

$$\text{failure frequency}_{\text{natural causes, adjusted}} = \text{failure frequency}_{\text{natural causes}} / \text{factor} \quad (26)$$

Only one measure can be applied.

Intolerable ground settling and stresses can be reasonably excluded through an evaluation	factor 10
Natural causes can be excluded	factor 100

10.4.5 *Mitigating measures for operational and other causes*

The measures in this paragraph have an effect on the 'operational failure and other' cause of failure. The failure frequency for operational failure and other causes of failure can be adjusted using the following formula:

$$\text{failure frequency}_{\text{operational causes, adjusted}} = \text{failure frequency}_{\text{operational causes}} / \text{factor} \quad (27)$$

Overpressure protection system based on the applicable Safety Integrity Level (SIL).

Applied SIL = Calculated SIL +1	factor 10
Applied SIL = Calculated SIL +2	factor 100

11 Technical documentation

11.1 Introduction

This chapter describes what documentation needs to be available in order to assess a QRA and specifies the report obligation of a QRA to a competent authority responsible for the Wm [Environmental Protection Act].

11.2 Obligation to report a QRA to a competent authority

Table 29 shows the items that need to be incorporated in a QRA report. Sensitive information may be present in the items noted as confidential. You can then consider supplying a second, public text. The second text must still be sufficient to provide third parties with the opportunity to form an opinion about safety, and where applicable the risks (see note 1).
Table 29 specifies the items for an independent QRA. A QRA will often be part of a more comprehensive information package. In such cases a reference to information included elsewhere in the package will of course be sufficient, for a process description.

Table 29 Summary of the items that need to be incorporated in a QRA.

	Subject	Confidential/public
1	**General report information**	
	– Administrative information: • name and address of the pipeline operator (according to Bevb) • name of the pipeline • name and address of the author of the QRA	Public
	– Reason for drawing up QRA	Public
	– Method used: • calculation package and version number	Public

	Subject	Confidential/public
2	**General description of the pipeline**	
	– Details of the pipeline (from RRGS [*Register of Risk Situations Hazardous Substances*]): • name of the pipeline owner • substance • diameter • pressure: maximum operating pressure • any mitigating measures • design standard incl. design factor	Public

	Subject	Confidential/public
2	**General description of the pipeline**	
	– Location of the pipeline, based on to-scale map(s). • Pipeline • north arrow and scale indication	Public
	– Description of specific situations (pipeline strip of land, structural works, pipeline tunnels, etc.)	Public

	Subject	Confidential/public
3	**Description of surrounding area**	
	– Local development and designated purpose for the area • land-use plans whether or not partly within the PR 10^{-6} contour and the area of influence.	Public
	– Current topographic map.	Public
	– A description of the population around the pipeline, specifying the way in which this description has come about (among other things, incidental development, ribbon development).	Public
	– Possible dangers from outside the pipeline which might have an effect on the pipeline (objects that increase the risk, neighbouring businesses/activities, flight paths, wind turbines).	Public
	– Roughness length and weather station used.	Public

	Subject	Confidential/public
4	**Description of possible risks to the surrounding area**	
	Summary overview of the results of the QRA which includes at least the following:	
	– Map with calculated location-specific risk, with contours for 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} and 10^{-8} (if present).	Public
	– Determination of sensitive and moderately sensitive objects within LSR 10^{-6}.	Public
	– FN curve with societal risk per pipeline for the kilometre of pipeline with the greatest exceedance of the orientation value applicable to transport pipelines.	Public
	– Justification for the determination of the worst case kilometre.	Public
	– FN data point at which the maximum exceedance of the orientation value occurs, including the exceedance factor.	Public

	Subject	Confidential/public
4	**Description of possible risks to the surrounding area**	
	– Damage distance for weather classes F1.5 and D5. (1% and 100% probability of dying in case of exposure).	Possibly confidential
	– Applicable preventative and repressive measures that are proposed in the QRA.	Public

Notes:

- The Safeti-NL study with which the risks are calculated is an integral part of the documentation. This file may contain some confidential information. Research must demonstrate whether the non-confidential information present in this file can be sensibly extracted. Working arrangements have been formulated for the interim period, which infer that the competent authority may view the Safeti-NL study at the company. Additionally, the most important characteristics of the QRA in relation to the risk calculations must be set out in a separate document. At least the points specified in Table 12 must be included in the document.
- The Safeti-NL study is also the basis for calculating societal risks and is therefore necessary for recalculating the FN graph as a part of the accountability obligation, for example in the case of a change in a land-use plan. According to the working arrangements that have been made, the relevant company will provide collaborative support in the required recalculation of the FN graph.

12 Appendix - Preconditions for reduction factors

A reduction factor associated with a measure, can only be applied when the measure complies with the preconditions that are applicable to it. This chap-ter sets out those preconditions. These are based on reference [3] and technical standard NEN3655. The basic principle is that the pipeline for petroleum products complies with the state-of-the-art conditions. The preconditions applicable to this principle are described first.

Preconditions for pipelines that comply with 'state-of-the-art'.
The most important condition for applying the failure frequency for the rupture scenario when the pipeline complies with the state-of-the-art, is the use of an effective safety management system (SMS) in accordance with Section 4(1) of the External Safety of Pipelines Decree (Bevb). The 'state-of-the-art' conditions for the various causes of failure are set out in Table 30. If one of the corresponding conditions is not met for a specific cause of failure, the appropriate failure frequency mentioned in Table 2 should be used for this cause of failure.

Table 30 Preconditions for state-of-the-art pipelines.

General	The use of an effective safety management system in accordance with Section 4(1) of the External Safety of Pipelines Decree (Bevb) and NEN3655.
Damage by third parties	• Clearly indicated above-ground markers for the pipeline that can be seen from every angle. One may deviate from this rule for practical limitations such as bends, thickets and obstacles. • Periodic communication with landowners to make and keep them aware of the presence of the pipeline. • Implemented KLIC [*Cables and Pipeline Information Centre*] / WION system with active reminder.
Mechanical	• Pipelines placed before 1980: mechanical assessment of the pipeline should be available. • Pipelines placed from 1980 onwards: none, are covered by significantly improved quality assurance and quality control (QA/QC) when a pipeline is laid.
Internal corrosion	Corrosion management system comprising: • Determination of product corrosivity. • Use of design measures based on corrosivity (for example, corrosion addition to wall thickness, use of corrosion inhibition, use of corrosion-resistant steel alloys for the pipe wall and, if necessary, internal coating/liner) • Effective monitoring programme (for example, monitoring product quality through sampling, injecting chemicals, sampling for metal loss).
External corrosion	Use of suitable coating and cathodic protection in accordance with NEN 3654. Effective monitoring

	programme for cathodic protection and the coating.
Natural causes	The structural design in relation to ground settling and stresses is known, documented and suitable measures have been taken.
Operational and other causes of failure	• Specified operating range in relation to flow rate, pressure, temperature, trip settings. • Automatic process monitoring and process safety devices. • Monitoring of all relevant DCS or SCADA data to continue operating within this operating range. • Changes to the operating range are only permitted using specified procedures, such as for modifications (Management of Change, MoC).

Preconditions for 'excavation damage by third parties'
A number of measures with corresponding reduction factors have been formulated for the 'excavation damage by third parties' cause of failure. This paragraph sets out the preconditions for the various measures.

Cluster 1
Active reminder.
The operator should contact the excavation contractor within 10 working days of the notification if they have not already done so.

Cluster 2
This relates to the *warning tape, protection* plates and the combination of *warning tape + protection plates measures*.

- The minimum distance between a pipeline and the protection material and the width of the cover must be recorded in a standard document. The combination of both factors (protection material and the distance between the material and the pipeline) must be such that the cover is effective and there is no contact with the pipeline even when employing the largest excavators that are in use at that time.
- The strength and suitability of different materials or structures should be demonstrated by field testing. The basic principle is that field testing is carried out in the same way as the field testing that was carried out to determine the reduction factor for protection plates [8]. The reduction factor can then be derived in the same way[8].
- If the cover on one pipeline also covers other pipelines, the other operators will have to be consulted in this case.
- This measure can only be implemented when the pipeline operator grants permission for taking these measures. It is primarily the effect of the cathodic protection and, for instance, the accessibility for coating inspections that are important in the considerations.

[8] If the measure proves to be effective in all experiments then when deriving the reduction factor it must be assumed that the measure was not effective for one experiment. This assumption is necessary because with a limited number of tests (n) it is not possible to rule out the (n+1)th test resulting in failure.

Cluster 3
This relates to measures where a management agreement has been made that contains a specific limitation.
Agreement with extensive restrictions:
- The land is taken out of use by leasing the land or by a strict management agreement that excludes all use of the land.
- The relevant part of the land is fenced-off.
- Markers are applied.
- The landowner must be contacted periodically (at least once each year) to discuss the situation concerned.
- During the (helicopter) inspections, the pipeline section to which the agreement applies, must be given specific attention.
- It must be possible to reject and never accept any request for excavation work by the owner and third parties. Immediate action is required upon receipt of a notification. It must be immediately clear to those handling the notification that a management agreement applies to the pipeline section concerned.
- If an agreement does not comply with all of the preconditions, the agreement will, at the very most, deliver the reduction factor for an agreement where digging/drilling is prohibited (see the 'Digging/drilling prohibited agreement' measure).

Agreement digging/drilling prohibited:
- An agreement that excludes excavation work, permits to use the land, for example, as pasture. Use as a parking or storage site, for instance, is also possible, if no excavation work is required to realise this.
- The landowner must be contacted periodically (at least once each year) to discuss the situation concerned.
- During the (helicopter) inspections, the pipeline section to which the agreement applies must be given specific attention.
- It must be possible to reject and never accept any requests for excavation work by third parties. Immediate action is required upon receipt of a notification of excavation work. It must be immediately clear to those handling the notification that a management agreement applies to the pipeline section concerned.
- If an agreement does not comply with all of the preconditions, the agreement will, at the very most, deliver the reduction factor for an agreement with limited restrictions (see the 'Limited restrictions agreement').

Agreement limited restrictions:
- In an agreement with limited restrictions, excavation work is not completely excluded but it is limited by the depth of the excavation.
- The landowner must be contacted periodically (at least once each year) to discuss the situation concerned.
- During the (helicopter) inspections, the pipeline section to which the agreement applies must be given specific attention.

Cluster 4
Fencing
- A fence must prevent entry into the immediate vicinity of the pipeline. If fencing only encloses the area near to the pipeline but

the area can easily be entered otherwise, then the fencing must be considered as a marking.
- This measure must be used in combination with marking.
- Accessibility of the pipeline must not be hindered.

Embankment.
- The embankment in relation to ground level is at least one metre high and this height must be maintained. Another option is to create an embankment 50 cm high, but in this case the embankment must be enclosed by a (metal) net that can provide sufficient resistance if excavation work will take place.
- The embankment must be continuous over the pipeline section for which the measure is applied. Because it is not possible to avoid crossing roads etc. the guideline is that at least 98% of the pipeline section concerned must be protected by an embankment. If less than 98% of the pipeline section is protected, a QRA must take specific account of the interruptions. The section that is not protected by an embankment must be protected in another way, by road paving for instance. In addition, additional marking must be placed at the start and end of the interruption.
- The measure must be used in combination with marking.
- The embankment must not have any impact on the integrity of the pipeline.
- Accessibility of the pipeline must not be hindered.

Ground-level barrier
- The distance between the barrier and the pipeline must be limited to one to two metres from the pipeline.
- Free-standing poles must be positioned maximally 20 cm apart.
- This measure must be used in combination with marking.
- Accessibility of the pipeline must not be hindered.

Cluster 5
Strict supervision of activities.
- In the event of a notification the pipeline operator must make immediate contact with the contractor performing the activities. During this contact, working agreements that are made should be recorded in writing. The pipeline operator must check the situation in situ daily, until contact is established with the contractor.
- If there is more than one week between the notification and the start of the activities, the pipeline operator must contact the contractor performing the activities every week (until the start of the activities).
- If the activities last longer than one week, the pipeline operator must carry out an additional in situ inspection every week (until the activities have been completed).
- Additional marking is to be used during the activities.
- It must be immediately clear to the pipeline operator's staff handling the notification that strict supervision applies to the pipeline section concerned. This is to be guaranteed in the procedure for dealing with the notifications.

Camera monitoring

- Monitoring must be continuous.
- It must be possible to monitor the entire pipeline section for which the reduction factor is used.
- When detecting (preparations of) activities in the proximity of the pipeline, it must be possible to intervene within minutes to stop these activities.
- Notified activities must be reported to the individual doing the monitoring to prevent false alarms.

Cluster 6

A precondition for this measure is that the cover must be effective on both sides of the pipeline. The cover must be applied in such a way that it can be expected that an excavating contractor who digs perpendicular to the pipeline continues to follow the soil surface and does not ignore the additional cover by following the level at excavation depth. For additional cover up to 20 cm, the cover must be applied over a minimum of 10 metres on either side of the pipeline. For additional ground cover exceeding 20 centimetres, the additional cover must be applied over a minimum of the right of way.

'In-line inspection (ILI)' preconditions

The measurement performance of the ILI must comply with the following requirements:

1. The probability of detection for potentially critical defects is at least 90%.
2. The detection threshold for material loss is 10% (overall wall thickness) and 15% (pitting) for Magnetic Flux Leakage (MFL) and 1.5 mm for Ultrasonic Testing (UT).
3. Defects of 20 x 20 mm or bigger should be detected.
4. ILI must be capable of identifying dents deeper than 2% of the internal diameter.

The inspection interval must be based on a thorough and standardised risk assessment with a fit-for-purpose (FFP) demonstration. The maximum ILI interval is 10 years.

To rate ILI as a measure, additional preconditions regarding general standards and procedures have been developed.

General

Which industry standard is applied for using ILI, depends on various considerations which should be a) aimed at preventing failure of a pipeline as a result of, for instance, internal and/or external corrosion and b) as long as the 'Fitness for Purpose' (FFP) and/or 'Fit for Service' (FFS) is confirmed in accordance with industrial Integrity Management (IM) principles. The operator should be able to demonstrate what is done with any defects that are observed and what considerations are used when doing so. Relevant features should be repaired in good time and the associated reports should be recorded. A proper effect analysis follows the same method as a proper risk assessment.

Available standards
There should be consistency with 'Specifications and requirements for intelligent pig inspection of pipelines, Version 2009, Appendix I' (see below) and the upper limits contained therein.
Operators using the reduction factors for ILI must have suitable procedures for the ILI/FFP/FFS/RBI/IM implementation process and acceptance criteria for anomalies that are detected ('features'). In the case of ILI this consistency comes from recent specifications such as those formulated by the POF (Pipeline Operator Forum):

1. Specifications and requirements for intelligent pig inspection of pipelines: version 2009.
2. Guidance documents to achieve In-Line-Inspection first run success:
   - Guidance on achieving ILI First Run Success, December 2012.
   - ILI Pipeline Questionnaire, December 2012.
   - ILI Check Lists, December 2012.
   - ILI Data Feedback Form, December 2012.
   - Guidance on Field Verification Procedures for In-Line-Inspection, December 2012.
   - ILI Field Verification Form, December 2012.

The following codes or guidelines can be used as reference for the standards for fitness-for-purpose analysis (FFP).

- NEN-3650:2012 Chapter 10. Requirements for pipeline systems.
- NEN 3655: safety management system (SMS) for pipeline systems for the transport of hazardous substances, 2020.
- API 579 -1 / ASME FFS-1. Recommended Practices for Fitness for Service.
- API 1160. Managing System Integrity for Hazardous Liquid Pipelines,
- ASME B31G. Manual for Determining the Remaining Strength of Corroded Pipelines,
- ASME 9909A-RPT-001. Pipeline Defect Assessment Manual,
- API 7910. Guide to methods for assessing the acceptability of flaws in metallic structures.
- PD 8010-4:2012. Pipeline systems. Steel pipelines on land and subsea pipelines. Code of practice for integrity management.
- Assessment of the Integrity of Structures Containing Defects, British Energy Generation, Report R/H/R6, Nuclear Electric.
- SINTAP. Fitness Structural INTegrity Assessment Procedures for European Industry,
- DNV-RP-F116. Integrity Management Systems of submarine pipeline systems, 2009,

Specifically for evaluating corrosion defects using ILI the following standards, among others, can be used as reference:

- ASME B31G + Modified B31G. Method for strength calculations/remaining service life calculations.
- RSTRENG. Computer program for calculating pipe corrosion.
- DNV-RP-F101. Corroded Pipelines · Pipeline Field Joint Coating and Field Repair of Linepipe Coating, 2010.

For a transparent working method and rating of the reduction factors, it is appropriate that the sector develops a complete guideline for the entire process based on existing standards.

N.B.: there are a number of 'non-piggable pipelines' where ILI cannot be used. There are however, developments to use existing techniques (CIPS/DCVG) and new analysis and evaluation techniques to determine the integrity status indirectly. With substantiation from the sector, such evaluation techniques could become eligible for consideration.

RBI option
The operator must demonstrate that the integrity of their pipeline is guaranteed. To do this they could opt for the RBI (Risk Based Inspection) approach. To this end, the way in which the RBI is set up must be recorded. When defects are detected, a proper analysis must lead to hypotheses on the possible causes. The fault/failure hypotheses must be linked to the consequences for the integrity and use of the pipeline (e.g. duration, conditions). This determines the inspection regime and the actions that stem from it (e.g. use restrictions, measurement frequency, monitoring the quality of the medium, etc.).

Elements that should form the basis of a RBI approach:
1. Formulating performance requirements and criteria, planning and selection tool.
2. Collection and integration of data: intended to facilitate a risk management approach. Data and an evaluation of the first pig run must already be available, and there are no changes in the operational management or conditions (MoC).
3. The subdivision of the pipeline (or pipeline network) into sections: the pipeline system is divided into sections where threats or consequences differ from the threats or consequences in other sections.
4. Identification of threats: the dangers that could result in a rupture, leak or interruption of supply have been identified. All features are analysed.
5. Risk assessment: the probability of failure as a result of a threat and the consequences of this failure are evaluated and multiplied and form a risk for each threat (and section).
6. Risk evaluation: the calculated risk is compared with an accepted risk level for a threat/section/pipeline.
7. Mitigation: a plan has been developed to manage the risks, linked to the relevant threats. All features are documented.
8. Evaluation and improvement: the process is continuous and is part of an improvement cycle.

'Internal corrosion - corrosivity of the medium' preconditions
The corrosivity must be substantiated and the quality of the medium should be monitored.
Inclusion of substantiation of 'inherently non-corrosive medium' and/or 'inherently non-corrosive pipe material' in the report is required.

'External corrosion - corrosivity of the pipe material' preconditions

The lack of corrosivity should be substantiated and the environment (acidification, bacteria, roots, excavation work, interference) should be monitored.
Inclusion of substantiation of 'inherently non-corrosive pipe material' in the report is required.

'Natural causes' preconditions

Impermissible settling/stresses can be excluded to a large extent
Impermissible settling and/or stresses can, to a large extent, be reasonably excluded by an evaluation:

- By checking the soil conditions, by inventorying critical areas (e.g. mining, structural works, peatlands).
- By creating a managed situation in critical areas, for example measuring/calculating stresses, measuring using settlement gauges / settlement rods, design with strain gauges, foundations, over-dimensioning of the structural design, lack of joints and other fittings, stress-free position.

Reports on the evaluation should be available within 1 year from claiming the reduction factor.

Natural causes can be excluded
Natural causes can be excluded when a substantiated report provides evidence of a solid and stable surface (sandy soils for example).

- By checking the soil conditions on the basis of which critical areas can be excluded (e.g. stable clay, sand).
- Impermissible settling and/or stresses are demonstrably excluded (e.g. based on case studies over many years).

'Operational and other failure' preconditions

1. Implementation of an overpressure protection system based on the applicable Safety Integrity Level (SIL) in accordance with IEC 61511 which has been derived from a hazard assessment of failure mechanisms including pressure/temperature relief and:
2. Implementation of a test regime for the overpressure protection system and proper training for the operators in operating the system and:
3. Ensuring that the operating envelope for the pipeline is not exceeded.

Preconditions: proper commissioning with, if possible, hydro-testing at implementation and periodical functional testing (part of SIL).

N.B.: although underpressure protection does not form part of the limitation of the probability of failure per se, it is expected that the SIL level for this protection corresponds with the overpressure protection.

13 References for Module C

[1] Det Norske Veritas (DNV), SAFETI-NL: the Dutch version of the pro-gramme Software for the Assessment of Flammable, Explosive and Toxic Impact version 8 (2019).

[2] Vliet, A.A.C. van, Laheij, G.M.H., Wolting, A.G., Risicoanalyse voor buisleidingen met brandbare vloeistoffen, RIVM-rapport 620120001/2006 (2006). {Vliet, A.A.C. van, Laheij, G.M.H., Wolting, A.G., Risk assessment for pipelines carrying flammable liquids, RIVM report 620120001/2006 (2006)}.

[3] I&M-brief, Aanvullende mitigerende maatregelen buisleidingen, referentienummer IENM/BSK-2014/74036, d.d. 28 maart 2014. {I&M letter, Additional mitigating measures for pipelines, reference IENM/BSK-2014/74036, dated 28 March 2014}. This letter is enclosed as an appendix to the Reference Manual Bevb Risk Assessments. The PIE re-ports quoted in this letter are available via www.velin.nl.

[4] RIVM-brief, Analyse faalkans CONCAWE-database, referentienummer 099-08/CEV Rik/mjd, d.d. 11 april 2008. {RIVM letter, Probability of failure analysis CONCAWE database, reference 099-08/CEV Rik/mjd, dated 11 April 2008}.

[5] RIVM-brief, Invloed diepteligging en wanddikte op de faalfrequentie voor leidingen met aardolieproducten en overige leidingen, referentienummer 165/11 CEV Vli/sij-3063, d.d. 26 juni 2011. {RIVM letter, Influence of depth and wall thickness on the failure frequency for pipelines carrying pe-troleum products and other pipelines, reference 165/11 CEV Vli/sij-3063, dated 26 June 2011}.

[6] Handreiking Verantwoordingsplicht Groepsrisico [Societal Risk Accountability Guidelines] which can be found on www.groepsrisico.nl

[7] Module IV van het rekenvoorschrift omgevingsveiligheid. {Module IV of the calculation instruction environmental safety} Available from: https://omgevingsveiligheid.rivm.nl/rekenvoorschrift-omgevingsveiligheid.

[8] Corder I., The application of risk techniques to the design and operation of Pipelines, IMechE., C502/016. 00 113 – 125 (1995)

Module D - Chemical product pipelines

Version 3.2
01 January 2021

Introduction

This module describes the way in which a QRA should be carried out for underground for (other) chemical product pipelines that are covered by the External Safety of Pipelines Decree [Besluit Externe Veiligheid Buisleidingen, hereinafter referred to as Bevb]. Where possible, consistency has been sought with the calculation methods for high-pressure gas pipelines (Module B) and for petroleum products and flammable liquids (Module C). In addition, a number of points tie in with the Purple Book [1] and the Reference Manual Bevi Risk Assessments [2].

The chemical product pipelines calculation method has been written for use in combination with the Safeti-NL [3] calculation package and results in individual risk contours and societal risk values as mentioned in the relevant laws and regulations. This module sets out the basic assumptions for the calculations using the Safeti-NL calculation package. In addition, it sets out how a risk analysis should be carried out using the Safeti-NL calculation package.

The chemical product pipelines calculation method has been formulated by RIVM in consultation with the operators. In situations where this module does not suffice, calculations should be carried out in accordance with best practice [4]. Please refer to the background documents associated with Safeti-NL for the models used in Safeti-NL [5].

14 Frameworks

14.1 Substances

Table 31 shows the hazardous substances that the RRGS [6] has classified as substances that are transported through pipelines and which are considered to be relevant to external safety in this methodology. The calculation method could also be applicable for (hazardous) substances other than those mentioned in Table 31. Here a check should be made whether these have modelling or hazard aspects other than those considered in the calculation method.

Table 31 Overview of hazardous substances of Module D.

Characteristic	**Aggregation status of the substance during transportation**		
	Liquid	*Pressurised liquefied gas*	*Gas*
Flammable	Isoprene 1,2-propylene oxide Non-stabilised condensate	Ethylene Butane Butene Propene Vinyl chloride LPG	Hydrogen
Toxic	Formaldehyde (46%)	Chlorine Ammonia	Carbon monoxide Hydrogen chloride
Flammable and toxic	Ethylene oxide		Syngas (H_2 and CO)
Inert and other			Carbon dioxide Nitrogen Oxygen

Notes:
- The flammable liquids are liquids with a boiling point of 308 K (35 °C) at the highest and a flash point lower than 273 K (0 °C).
- The list of substances in Table 1 is not exhaustive. For example, natural gas, which does not comply with the description given in Section 1 of Revb [External Safety (Pipelines) Order], could fall under this methodology.
- Carbon dioxide and ammonia are, in principle, flammable and toxic but because they are low reactive substances only the toxic properties are taken into consideration [2].
- The liquids aniline, MDI and caustic soda are not (acutely) toxic nor do they have a flash point higher than 60 ºC. For these types of pipelines the competent authority decides whether or not a risk analysis should be carried out.
- If the aggregation status of a substance is other than described in Table 1, the operator should submit a proposal to the competent authority on how the substance should be modelled.

- Carbon dioxide can also be transported as liquid or supercritical gas.
- Based on its boiling point ethylene oxide is considered to be a liquid, but it is modelled as a pressurised liquefied gas (see section 15.7.2).

15 Calculation method

15.1 Outflow scenarios

The following scenarios are considered in the calculation method:

Table 32 Scenarios for underground pipelines.

Scenario
Rupture of the pipeline
Leak with an effective diameter of 10% of the nominal internal diameter, max. 20 mm

Please note: the leak scenario is not included for pipelines carrying flammable substances and for pipelines carrying formaldehyde. See section 19.1 for further details.

15.2 Failure frequencies

The failure frequencies for a pipeline apply to the pipeline including flanges, welds and valves but excluding pumps. The standard failure frequencies for underground pipelines are shown in Table 33, the corresponding cause-of-failure distribution is shown in Table 34 [7]. See Chapter 17 for further details.

Table 33 Scenarios and failure frequencies for underground pipelines.

Scenario	Failure frequency (km^{-1} $year^{-1}$)
1. Rupture of the pipeline	1.5×10^{-4}
2. Leak with an effective diameter of 10% of the nominal diameter, maximum 20 mm	4.5×10^{-4}
Total	6.0×10^{-4}

Table 34 Cause-of-failure distribution for pipelines with chemical products.

Cause of failure	Failure frequency			Proportion (%)	
	Rupture	*Leak*	*Total*	*Rupture*	*Leak*
Damage by third parties	7.19×10^{-5}	9.86×10^{-5}	1.71×10^{-4}	47.9	21.9
Mechanical	3.23×10^{-5}	1.45×10^{-4}	1.77×10^{-4}	21.5	32.2
Internal corrosion	5.71×10^{-6}	4.40×10^{-5}	4.97×10^{-5}	3.8	9.8
External corrosion	1.72×10^{-5}	1.32×10^{-4}	1.49×10^{-4}	11.5	29.3
Natural causes	9.15×10^{-6}	1.35×10^{-5}	2.27×10^{-5}	6.1	3.0
Operational/other	1.38×10^{-5}	1.71×10^{-5}	3.09×10^{-5}	9.2	3.8
Total	$\mathbf{1.5 \times 10^{-4}}$	$\mathbf{4.5 \times 10^{-4}}$	$\mathbf{6.0 \times 10^{-4}}$	**100**	**100**

Notes:
- In the failure frequency for the rupture scenario the effect of the excavation contractors regulation (WIBON) is taken into account

by reducing the number of ruptures as a result of damage caused by third parties (external interference) by a factor of 2.5 [8].
– The depth is taken into account in the 'Damage by third parties' cause of failure [7]. The adjusted failure frequency is:

$$\text{failure frequency}_{\text{damage by third parties, adjusted}} = \text{failure frequency}_{\text{damage by third parties}} / \text{factor} \quad (28)$$

where:

$$\text{factor} = e^{-2.4 \times (0.84 - z)} \quad (29)$$

and:
z = depth (m).

Cover transitions of 20 cm or more should be included in the calculations. In addition, cover transitions of 10 cm or more that continue over a pipeline distance of 50 metres or more should be included. You may deviate from these requirements if the depth has been chosen conservatively and no difficulties arise. This could apply to pipelines in rural areas, for instance. Accurate calculations are only necessary if difficulties can arise, for instance in the event of a change in a land-use plan permitting a (moderately) sensitive object in the vicinity of the pipeline.

15.3 Scenario modelling

The standard way of modelling in Safeti-NL [3], reported in Table 35, and the settings shown in Table 36, must be used for the calculations. See section 19.2 for further details.

Table 35 Use of scenarios and models in Safeti-NL.

Scenario	Safeti-NL model
Line rupture	
Gas	Vessel → Long Pipeline (Vessel → Long Pipeline → UDS[9] for H_2)
Liquid	Vessel → Catastrophic rupture (Vessel → UDS for formaldehyde)
Pressurised liquefied gas	Vessel → Long Pipeline
Hole in pipeline	Vessel → Leak

Table 36 Various Safeti-NL parameter settings.

Parameter	Safeti-NL settings
Temperature	9.8 ºC with the exception of ethylene (see section 15.6) and ethylene oxide (see section 15.7.2)
Pressure	Maximum operating pressure for the pipeline (see section 18.2)

9 UDS = User Defined Source. The input for this scenario is taken from the output from another scenario. The initial results from this scenario can be manually adapted in the UDS scenario. The UDS scenario is obtained using the *'Create Source'* option.

Parameter	Safeti-NL settings
Probability scenario	0.25 for rupture and 0.75 for leak[10] [7]
Probability of immediate ignition10	See Table 8
Outflow height	0.01 m (see section 16.2.1)
Outflow direction	Vertical (see section 16.2.1)
Method for calculating average rate	Flammable substances: average between time 0-20 sec. Toxic substances: up to ten rates, expected number of average rates 10 (see section 16.2.3)
Pipeline surrounding	All but hydrogen: Above ground Hydrogen: Buried
Distance to break	The distance to break will be determined automatically when using Auto-generated sections.
Relative hole size for rupture	1 (for rupture)
Absolute hole size for leak	Diameter of the leak with a maximum of 20 mm

Notes:

- The relative hole size (relative aperture) is equal to 1 for rupture. The corresponding hole size then is $\sqrt{2}$ × the pipeline diameter, mimicking a release from both pipe ends.

15.4 Event trees

When hazardous substances are released from underground pipelines, various consequential effects are possible. The occurrence of these effects depends, among others, on the hazard aspects of the substance being transported and the degree to which immediate or delayed ignition occurs. The effects that occur with a rupture or leak are shown in Table 37. The corresponding probabilities of ignition are shown in Table 8. See section 19.3 for further details.

Table 37 Normative events for rupture or leak in a pipeline.

Hazard classification	Immediate ignition	Delayed ignition	No ignition
Flammable			
Gas	Jet fire	N/A	N/A
Liquid	Pool fire	Flash fire + pool fire	N/A
Pressurised liquefied gas	Jet fire	N/A	No effect
Toxic			
Gas	N/A	N/A	Toxic effects
Liquid	N/A	N/A	Toxic effects

[10] Please note: in the case of pressurised liquefied gases that are only flammable it is only the immediate ignition that is included. To prevent delayed ignition also being included accidentally, the probability of immediate ignition must be set to 1 and the likelihood of the scenario concerned must be multiplied by the actual value for immediate ignition (0.3 for rupture and 0.14 for leak). For rupture and leak this results in a likelihood of 0.075 (0.25 × 0.3) and 0.105 (0.75 × 0.14) respectively. Also see section 19.3.

Hazard classi-fication	Immediate ignition	Delayed ignition	No ignition
Pressurised liquefied gas	N/A	N/A	Toxic effects
Flammable and toxic			
Gas	Jet fire	Toxic effects	
Liquid	Flash fire + pool fire	Toxic effects	

Notes:

- In the case of substances that are both flammable and toxic, the flammable effects are considered with immediate ignition and the toxic effects are considered when no immediate ignition takes place. Toxic effects that occur after the ignition of a flammable cloud are not included. It is assumed that in this case the plume will rise and will not cause any further lethal toxic effects at ground level.
- For flammable/combustible liquids, a site boundary must be specified in Safeti-NL if the immediate ignition probability is less than 1. For these flammable/combustible liquids the distance to the site boundary should be 5 metres.

Table 38 Probabilities of ignition for rupture and leak.

	$P_{immediate}$	$P_{delayed}$
Gases		
- rupture and leak	1*	0
Pressurised liquefied gases		
- rupture	0.3	0
- leak	0.14	0
Liquids (K_0)		
- rupture and leak	0.065	0.935

* Only relates to hydrogen; given the low ignition energy a rupture is expected to always lead to ignition.

15.5 Modelling gases

15.5.1 Modelling hydrogen

For hydrogen, the crater model is used. For the pipeline surrounding characteristics, the ‘buried’ option is selected and the soil type and depth of the pipeline are supplied as input. For the leakage scenario, the option puncture at the top is selected. For all other gases, calculations can still be made without a crater model. For the pipeline surrounding characteristics, the option ‘above ground’ is selected.

15.6 Modelling pressurised liquefied gases

The standard modelling of pressurised liquefied gases is described in section 15.3 and section 15.4. For pressurised liquefied gases, the crater model is not yet used and the option ‘above ground’ is used for the pipe-line surrounding characteristics.

A different temperature should be used for ethylene. Ethylene is a substance with a critical temperature of 9.19 ºC and is modelled at a slightly lower temperature (9 ºC) so that it behaves as a liquid and not as a supercritical fluid. See section 19.5 for further details.
For pressurised liquefied gases that are only flammable, the immediate ignition probability in Safeti-NL should be set to 1 (see footnote 10). The ignition probability (Table 8) shall then be factored into the scenario failure frequency.

15.7 Modelling liquids

When modelling liquids the greatest degree of consistency possible has been sought with the methods for petroleum products pipelines (Module C). See section 19.6 for further details. An exception to this is ethylene oxide, which has been modelled as pressurised liquefied gas (section 15.7.2).

15.7.1 Flammable liquid

The amount of liquids that rises above ground as a result of a rupture of the pipeline is the same as the sum of the amount of liquids that is released within the pump shut-down time (V_1) and the amount of liquids that is re-leased as a result of the compressed liquid expanding (the so-called line-pack, V_2).

1. The amount of liquid released within the pump shut-down time (V_1).
The amount of liquids that is released within the pump shut-down time is equal to:

$$V_1 = \Phi_{pump} \cdot t \qquad (30)$$

where

Φ_{pump}	=	maximum pumping rate (m^3/s)
t	=	time from the rupture occurring until the pump shuts down or until the valves are closed in the pipeline(s).

2. Outflow as a result of the compressed liquid expanding (V_2).
The line-pack is calculated using the following formula:

$$V_2 = \pi/4 \cdot D^2 \cdot L \cdot P \cdot C_e \qquad (31)$$

where:

V_2	=	increase in the volume of the product (m^3);
D	=	internal diameter of the pipeline (m);
L	=	total pipeline length (m);
P	=	operating pressure at the rupture site (N/m^2);
C_e	=	compressibility of the liquid ($= 0.88 \cdot 10^{-9}$ m^2/N).

When a pipeline is full and pumping is not taking place, all outflow in the event of rupture of the pipeline will be the result of the compressed liquid expanding (V_2).

It is recommended that where necessary the subsequent delivery as a result of an inclined pipeline and additional outflow from a pipeline resulting from backflow from the receiving storage tanks (V_3) should be taken into account.

Rupture of a pipeline carrying flammable liquid is modelled as the instantaneous failure of a vessel at atmospheric pressure or under a very slight overpressure. In the event of immediate ignition only a pool fire is taken into consideration, because the effect area of the combustion of the flashed liquid falls within the effect area of the pool fire. In the event of delayed ignition, in addition to pool fire, a flash fire is also taken into account because the flashed liquid has time to drift away and ignite at a distance. The size of the pool is determined by the amount of liquid that has flowed out $V_1 + V_2$ (+ any V_3) that forms a pool which is 0.05 m deep (Module C). This pool is entered as a bund.

15.7.2 *Flammable and toxic liquid - rupture*

This only relates to ethylene oxide (EO). The substance is not modelled as a liquid but as a pressurised liquefied gas by using a temperature of 12ºC during modelling. The probability of ignition is 0.3, which corresponds with the probability of ignition for pressurised liquefied gases. See section 19.6.2 for further details.

15.7.3 *Flammable and toxic liquid - leak*

In line with the rupture scenario, the temperature of 12 ºC is also used for the leak scenario. The probability of ignition is 0.14, which corresponds to the probability of ignition for pressurised liquefied gases. See section 19.6.2 for further details.

15.7.4 *Toxic liquid*

The only toxic liquid that is transported is a formaldehyde solution subject to different modelling. In order to determine the risks of the formaldehyde solution, the surface area of the pool that will form must be determined first. The evaporation of the pool can then be determined. See section 19.6.3 for further details.

1. Determine the surface area of the pool.
   The surface area of the pool in the event of rupture can be calculated using the formulas shown in section 15.7.1. The pool depth that should be used is 0.05 m.
2. Calculate the source term qv (kg/s) as a result of evaporation of the pool ignoring heat transfer from the ground, radiation and convection [9]. The parameters and some of the values to be entered are shown in Table 39.

$$q_v = C_{m\&m} \times u_{w,10}^{0.78} \times (2 \times r)^{-0.11} \times Sc^{-0.67} \times P_v \times A \times \mu/(R \times T_{ps} \qquad (32)$$

Next, the evaporation speed should be entered as a source term in a UDS scenario, Pool Source – Radius type. In the case of pipelines with formaldehyde solution, only the rupture scenario is included (see section 19.1).

Table 39 Parameters for determining evaporation of the pool for formaldehyde solutions.

Parameter	Description	Value
$C_{m\&m}$	constant	0.004786 ($m^{0.33}$ $s^{-0.22}$)
k_m	Mass transfer coefficient	comparison 7
P_v	Formaldehyde partial vapour pressure[11]	56 N m^{-2}
r	Radius of pool of liquid	(m)
R	Gas constant	8.314472 J mol^{-1} K^{-1}
Sc	Schmidt number[12]	0.8
T_{ps}	Temperature of pool of liquid	283 K
$u_{w,10}$	Wind speed at a height of 10 metres	5 m s^{-1}
μ	Molecular weight	30.0 kg mol^{-1}
A	Pool surface area	m^2

15.8 Societal risk

The societal risk is calculated for the worst case kilometre on the line. When a pipeline has a total length of less than 1 km the FN curve is calculated for the entire pipeline.
The worst case kilometre has to be determined manually in Safeti-NL. In general, the societal risk is the largest in the segment with the highest population density along the line combined with the largest area of influence along the line. The determination of the worst case kilometre must be specifically substantiated by the author. Also see section 19.7.
The population groups to be included in the QRA are set out in the Societal Risk Accountability Guidelines [10].

11 The partial vapour pressure of a 40% formaldehyde solution at 10 ºC (Ullman).
12 Typically, the value of Sc is in the range of 1 - 2.5 (Report No. HAZMAT 93-3). Using the value 0.8 results in a small overestimate of the source term.

16 Model parameters

16.1 Introduction

In a risk assessment using the Safeti-NL QRA calculation package, a number of selections need to be made and a large number of parameter settings should be entered. This chapter describes a number of selections in the modelling process and the parameters that are relevant in the risk calculations for chemical product pipelines. The description observes a distinction between three types of parameters:

- Parameters which the user can change to align the calculation with the pipeline-specific and location-specific conditions (QRA-specific parameters, section 16.2).
- Parameters which the user cannot change, but which are characteristic of a QRA calculation in the Netherlands (section 16.3).
- Parameters which are substance-specific and cannot be changed by the user in the Netherlands (section 16.4).

In addition, there are other parameters which the user cannot change, but which belong with the calculation model, and parameters which do not impact on the calculation results but only determine the presentation of (intermediate) results. These parameters are set out in the documentation of the calculation package.

16.2 QRA-specific parameters

16.2.1 Settings to be used by default

The parameters in this category can be changed to align the calculation with the specific conditions under which the underground pipeline is operated. Table 40 contains an overview of the settings that should be used by default for various QRA-specific parameters. See section 19.8.1 for further details.

Table 40 Settings to be used by default in Safeti-NL[13].

Parameter	Default setting
Direction of the outflow underground	Vertical
Height of the outflow	0.01 m
Roughness length of the pipeline	45 μm
Roughness length of the free field surface area	≤ 300 mm

Notes:

– A tool that can be used to determine the roughness length of a location is available on the website of the Ministry of Infrastructure and Water Management. Enter the search term 'ruwheidskaart' on www.rijksoverheid.nl and download the Ruwheidskaart.zip zip file. This zip file contains a text file from

[13] Whilst it is true that these parameters could be adapted by the user, the settings shown are those prescribed for this method.

which you can take the x and y coordinates (RDM) of the bottom-left corner (south-west corner) of the 1x1 km square. The third column contains the z^0 value (roughness length) in metres.

16.2.2 *Loss of pressure as a result of valves and bends*

Loss of pressure in a pipeline due to the presence of valves and fittings is not taken into account in the calculation.

16.2.3 *Time-varying release*

In the event of a rupture of a pipeline, the outflow rate will vary within time. This can be taken into account in Safeti-NL by using a time-varying flow rate.
In the case of flammable (pressurised liquefied) gases the outflow rate for a rupture is assumed to be the average over the period 0-20 seconds. For toxic (pressurised liquefied) gases, a time-varying release is assumed for a rupture, with 10 time segments. See section 19.8.2 for further details.
A pool is modelled for a rupture of a pipeline carrying flammable and/or toxic liquid, without time-varying release in relation to modelling.

16.2.4 *Weather station and parameters*

The weather station that is representative of (part of) the pipeline in terms of location must be selected. The user has a choice of weather stations as specified in Table 41.

Table 41 Weather stations

Name				
Beek	Eindhoven	Leeuwarden	Twente	Woens-drecht
Deelen	Gilze-Rijen	Rotterdam	Valkenburg	Ypenburg
Den Helder	Hoek van Holland	Schiphol	Vlissingen	
Eelde	IJmuiden	Soesterberg	Volkel	

Default values for a number of meteorological parameters can be found in Table 42. The values are yearly averages. It is assumed that the temperature of the substance that is transported is the same as the average year temperature of the substrate/bund, being 9.8 ºC. The exceptions to this are ethylene (see section 19.5) and ethylene oxide (see section 19.6.2)

Table 42 Default values for a number of meteorological parameters.

Parameter	Day default value	Night default value
Ambient temperature	12 °C	8 °C
Substrate/bund temperature	9.8 °C	9.8 °C
Water temperature	9.8 °C	9.8 °C
Air pressure	101550 N/m^2	101550 N/m^2
Relative humidity	76.5%	86.3%
Global radiation	0.25 kW/m^2	0 kW/m^2
Fraction of a 24-hour period	0.44 (08:00 – 18:30)	0.56 (18:30 – 08:00)
Mixing height	See note	

Note:
- The default values for the mixing height are 1500 metres for weather category B3, 500 metres for weather category D1.5, D5 and D9, 230 metres for weather category E5 and 50 metres for weather category F1.5.

16.2.5 *Distribution of presence inside and outside*

The distribution of the population inside and outside buildings is set out in Table 43. These values apply to residential and industrial areas, unless other information is available. In relation to recreational areas, the type of recreational activity is determinative for the distribution of population inside and outside buildings.

Table 43 Distribution of population inside and outside throughout the day and night.

	Inside	Outside
Day	0.93	0.07
Night	0.99	0.01

16.2.6 *Modelling people for events*

People who are only present for part of the year (or of the daytime period), such as in recreational areas or for events, must be included in the calculation if the contribution to the societal risk is relevant. Such groups are included in Safeti-NL by defining different rows for periods of time with different numbers of people present, taking the required accuracy into account. See section 19.8.3 for further details.

16.3 Parameters specific to a QRA in the Netherlands

The parameters in this category cannot be changed.

16.3.1 *Duration*

Dispersion models are based on an averaging time constant that is needed to calculate the maximum concentration and the width of the plume. The default values for the averaging time constant t_{av} are [2]:
- flammable substances t_{av} = 18.75 s
- toxic substances t_{av} = 600 s

The maximum outflow time in Safeti-NL is 1800 s. This also applies to the maximum time for evaporation of the pool. It is assumed that intervention has been successful after 1800 s.

The exposure time for thermal radiation is a maximum of 20 s. Exposure time for toxic substances is limited to a maximum of 1800 s. The possibility of an evacuation within 1800 s is not included in the QRA. See section 19.9.1 for further details.

16.3.2 *Height for calculating the effects*

The toxic dose and thermal radiation dose are calculated at a height of one metre.

16.3.3 *Lethality - Probits*

The probability of dying, P_{lethal}, is calculated using the following probit:

$$P_{lethal} = 0{,}5 \times \left[1 + erf\left(\frac{\mathrm{Pr}-5}{\sqrt{2}}\right)\right] \qquad (33)$$

where

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \qquad (34)$$

The probit for exposure to toxic substances is indicated using the relationship:

$$\mathrm{Pr} = a + b \ln\left(\int C^n \, dt\right) \qquad (35)$$

using

PR	probit associated with the probability of dying	(-)
a, b, n	constants for the toxicity of a substance	(-)
C	concentration at time t	(mg/m^3)
t	exposure time	(minutes)

The calculation of the lethality for the location-specific risk and the societal risk is set out in Table 44 [2]. The minimum value of P_{lethal} that is still included in the calculation is 0.01.

Table 44 Probability of dying for toxic substances.

Area	Location-specific risk	Societal risk inside	Societal risk outside
$P_{lethal} \geq 0.01$	P_{lethal}	See Note	P_{lethal}
$P_{lethal} < 0.01$	0	0	0

Note:

- The probability of dying for people inside (societal risk) is calculated using the probit relationship based on indoor exposure. The indoor exposure is calculated with a standard ventilation rate of one per hour. It is assumed that people will go outside again after some time; more particularly 1800 s after the outdoor concentration starts to decreases.

The probability of dying, P_{lethal}, for exposure to thermal radiation (pool fire, jet fire) is given by the probit relationship:

$$Pr = -36{,}38 + 2{,}56 \ln\left(\int Q^{4/3}\, dt\right) \qquad (36)$$

using

Pr	probit associated with the probability of dying	(-)
Q	thermal radiation at time t	(W m^{-2})
t	exposure time	(s)

The calculation of the lethality for the location-specific risk and the societal risk is set out in Table 45 [2]. A dose is defined as a function of exposure time t and intensity I, namely $t \cdot I^{4/3}$ with the unit $s\text{-}(W/m^2)^{4/3}$. The dose value $2.29 \cdot 10^7$ $s \cdot (W/m^2)^{4/3}$ corresponds to an exposure time t = 20 s and an intensity I = 35 kW/m^2. The minimum value of P_{lethal} that is still included in the calculation is 0.01.

Table 45 Probability of dying for flammable substances.

Area	**Location-specific Risk**	**Societal risk inside**	**Societal risk outside**
Flame zone	1	1	1
$t \cdot I^{4/3} \geq 2.29 \cdot 10^7$ $s \cdot (W/m^2)^{4/3}$	1	1	1
$t \cdot I^{4/3} < 2.29 \cdot 10^7$ $s \cdot (W/m^2)^{4/3}$	P_{lethal}	0	$0.14 \times P_{lethal}$

Note:
- The maximum exposure time to thermal radiation is 20 s.

16.3.4 *Wind turbine influence*

The effect of wind turbines must be included in the determination of the risk. A method for determining the effect of wind turbines is specified in [11].

16.4 Substance-specific parameters

16.4.1 *Probit relationships for toxic substances*

The probits to be used for the toxic substances concerned are included in Table 46.

Table 46 Probit relationships for the toxic substances concerned.

Substance	Cas No.	a (conc. in mg/m³)	a (conc. in ppm)	b	n
Ammonia	7664-41-7	-15.6	-16.21	1	2
Chlorine	7782-50-5	–6.35	–4.81	0.5	2.75
Ethylene oxide	75-21-8	–6.8	–6.16	1	1
Carbon monoxide	630-08-0	–7.4	–7.21	1	1
Hydrogen chloride	7647-01-0	-37.3	-35.62	3.69	1

Notes:
- The probit for formaldehyde has been approved by the probits expert group but not specified by the Ministry of Infrastructure and the Environment. That is why this probit does not yet have a formal status and is not included in Table 16. The proposed probit relationship can be requested from RIVM using the email address safeti-nl@rivm.nl.
- In Safeti-NL the ppm unit is used to indicate the concentration. See section 19.9.2 for further details.

16.4.2 *Probit relationship for nitrogen*

The release of large quantities of inert substances such as nitrogen can lead to suffocation. The following probit relationship can be used for inert substances:

$$Pr = -65{,}7 + \ln\left(\int C^{5{,}2}\, dt\right) \qquad (37)$$

using

Pr	probit associated with the probability of dying	(-)
C	concentration at time t	(ppm)
t	exposure time	(minutes)

16.4.3 *Probit relationship for carbon dioxide*

Carbon dioxide is a substance that has a toxic effect in addition to a suffocating effect. This is why the probit relationship for inert substances cannot be used. However, a suitable probit relationship has not yet been approved for carbon dioxide. See section 19.9.3 for further details.

16.4.4 *Probit relationship for oxygen*

Oxygen is a substance which increases fire hazard, and high concentrations lead to an increased probability of fire in the surrounding area. In general, the risks associated with the transportation of oxygen in underground pipelines are negligible. It is only when very large quantities are released that it is meaningful to include the escaped oxygen in the risk analysis. An effective probit relationship cannot be deduced for oxygen. It is necessary to determine whether a pipeline carrying oxygen is relevant to external risk based upon the following effect levels:

P_{lethal} = 0.1 at oxygen concentrations in the air greater than 40 vol%
P_{lethal} = 0.01 at oxygen concentrations in the air between 30 and 40 vol%

$P_{lethal} = 0$ at oxygen concentrations in the air between 20 and 30 vol%

An oxygen concentration of 40 vol% in air corresponds with an additional quantity of oxygen of 24.1 vol% (241,000 ppm) in the dispersion calculation; 30 vol% oxygen in air corresponds with 11.4 vol% (114,000 ppm) in the dispersion calculation.

17 Measures

17.1 Introduction

Mitigating measures provide the opportunity to reduce the risks of a pipeline. The additional mitigating measures described in this chapter apply to all underground pipelines carrying flammable liquids and pipelines with chemical products. Exceptions are[14]:

- Above-ground pipelines.
- 'Hot Lines' with an operating temperature above 100 °C. This includes pipelines where the products are heated and are transported in heavily insulated pipelines or where the pipe system has external heat sources to reduce the viscosity of the product or where the products extracted as a result of prospecting are at temperatures above 100 °C.
- Plastic pipelines.

The measures mentioned can be used for both rupture and leak frequency. Any exceptions are stated specifically.
A number of preconditions must be met before a reduction factor can be applied. The preconditions are set out in the appendix. The definition of the factors and preconditions is based, in part, on pragmatic policy decisions. The policy-related justification of the derived factors and preconditions is set out in [7].

The measures that are described in this chapter limit the probability of failure. Measures that limit the effects are not described but should be taken into consideration in the calculation method. This relates in particular to measures that detect failure of the pipeline and intervene accordingly, as a result of which the outflow duration can be limited (pressure relief devices for example).

17.2 Pipelines that comply with the state-of-the-art conditions

The failure frequency and cause-of-failure distribution in
Table 47 may be used for pipelines that comply with the state-of-the art conditions (see the appendix). When a specific cause of failure has not been investigated in detail or when one of the associated conditions has not been met, the failure frequency mentioned in section 15.2 should be used for this cause of failure.

Table 47 Failure frequency and cause-of-failure distribution for chemical product pipelines that comply with 'state-of-the-art'.

	Failure frequency [km.year^{-1}]			**Proportion (%)**	
Cause of failure	*Rupture*	*Leak*	*Total*	*Rupture*	*Leak*
Damage by third parties	1.77×10^{-5}	2.63×10^{-5}	4.40×10^{-5}	47.9	21.9
Mechanical	7.96×10^{-6}	3.86×10^{-5}	4.66×10^{-5}	21.5	32.2

[14] The failure frequencies included in this module do not apply to these pipelines either.

	Failure frequency [km.year^{-1}]			Proportion (%)	
Cause of failure	*Rupture*	*Leak*	*Total*	*Rup-ture*	*Leak*
Internal corrosion	1.41×10^{-6}	1.17×10^{-5}	1.31×10^{-5}	3.8	9.8
External corrosion	4.25×10^{-6}	3.52×10^{-5}	3.95×10^{-5}	11.5	29.3
Natural causes	2.26×10^{-6}	3.60×10^{-6}	5.86×10^{-6}	6.1	3.0
Operational	3.40×10^{-6}	4.56×10^{-6}	7.96×10^{-6}	9.2	3.8
Total	**3.70×10^{-5}**	**1.20×10^{-4}**	**1.57×10^{-4}**	**100**	**100**

Note:
- The depth is taken into account in the 'Damage by third parties' cause of failure [7,12]. The way this should be done is set out in section 15.2.

17.3 Mitigating measures for preventing damage by third parties

The failure frequency for damage by third parties can be adjusted, given the measures to be taken and measures taken using the following formula:

$$\text{failure frequency}_{\text{damage by third parties, adjusted}} = \text{failure frequency}_{\text{damage by third parties}} / \text{factor} \quad (38)$$

where:

$$\text{factor} = \text{factor}_{\text{cluster 1}} \times \text{factor}_{\text{cluster 2}} \times \text{factor}_{\text{cluster 3}} \times \text{factor}_{\text{cluster 4}} \times \text{factor}_{\text{cluster 5}} \times \text{factor}_{\text{cluster 6}} \times \text{factor}_{\text{cluster 7}} \quad (39)$$

Only one measure can be selected per cluster for clusters 2 to 5 inclusive.

17.3.1 Cluster 1 - Active reminder

No measure from cluster 1 or pipeline that complies with the state-of-the-art conditions (see section 17.2)	factor: 1
Active reminder.	factor: 1.2

17.3.2 Cluster 2 - Cover using protective material

This relates to measures where underground cover has been applied to the pipeline.

No measure from cluster 2.	factor: 1
Warning tape.	factor: 1.67
Protection plates.	factor: 5
Warning tape + protection plates.	factor: 30

17.3.3 Cluster 3 - Management measures

Management measures relate to the limitation and/or exclusion of excavation work using a management agreement with the land owner. The management agreement contains one of the following restrictions:

No measure from cluster 3.	factor: 1
Extensive restrictions.	factor: 100

Digging/drilling prohibited**.**	factor: 10
Limited restrictions.	factor: 1.6

17.3.4 *Cluster 4 - Physical barriers at ground level*

These are measures that make clear that, should excavation work take place, the activities are not allowed to be carried out.

No measure from cluster 4.	factor: 1
Fencing.	factor: ∞
Embankment.	factor: 10
Barrier at ground level.	factor: 8

17.3.5 *Cluster 5 - Other measures*

The measures in cluster 5 relate to measures that operate relying on the Excavation Contractors Regulation. A single measure may be selected for cluster 5.

No measure from cluster 5.	factor: 1
If no measure from cluster 1	
Strict supervision of activities.	factor: 3
Camera monitoring.	factor: 2.6
When using active reminder from cluster 1	
Strict supervision of activities.	factor: 2.5
Camera monitoring.	factor: 2.4

In the case of pipelines that comply with the state-of-the-art conditions the factors for cluster 5 must be based on the factors stated in 'When using active reminder from cluster 1'.

17.3.6 *Cluster 6 - Additional ground cover*

An overview of the reduction per 10 cm of additional ground cover is shown in Table 48.

Table 48 Effect of increasing ground cover.

Additional ground cover (m)	**Reduction factor**
0.1	1.3
0.2	1.6
0.3	2.1
0.4	2.6
0.5	3.3
0.6	4.2
0.7	5.4
0.8	6.8
0.9	8.7
1.0	11.0

17.3.7 *Cluster 7 - Wall thickness*

Wall thickness excluding corrosion allowance is at least 15 mm.	factor 10

The reduction of the probability of failure in the rupture scenario is added to the failure frequency for the leak scenario. As a result of this the total failure frequency does not change.

17.4 Mitigating measures for the other causes of failure

For the other causes of failure no more than one measure per cause of failure can be rated, even if there are a number of measures that could have an effect on the same cause of failure.

17.4.1 *Mitigating measures to prevent mechanical failure*

The measures in this paragraph have an effect on the 'mechanical failure' cause of failure. The failure frequency for mechanical failure can be adjusted, given the measure to be taken and measures that have been taken using the following formula:

$$\text{failure frequency}_{\text{mechanical failure, adjusted}} = \text{failure frequency}_{\text{mechanical failure}} / \text{factor} \quad (40)$$

Only one measure can be rated.

Reducing the maximum permitted operating pressure to a level where the operational stress falls below 30% SMYS (Specified Minimum Yield Stress).	factor 10

The effect of this measure is that failure can practically only occur as a result of a leak and almost never as a result of rupture. The reduction of the probability of failure for the rupture scenario is added to the probability of failure for the leak scenario. As a result of this the total probability of failure does not change.

Carrying out a suitable high-resolution metal loss In-Line Inspection (ILI) combined with thorough defect analysis and repair if necessary.	factor 10

17.4.2 *Mitigating measures to prevent internal corrosion*

The measures in this paragraph have an effect on the 'internal corrosion' cause of failure. The failure frequency for internal corrosion can be adjusted using the following formula:

$$\text{failure frequency}_{\text{internal corrosion, adjusted}} = \text{failure frequencyi}_{\text{nternal corrosion}} / \text{factor} \quad (41)$$

Only one measure can be rated.

The medium to be transported is inherently demonstrably totally non-corrosive in relation to the pipeline material (and vice versa).	factor ∞

The medium to be transported has been made sufficiently non-corrosive in relation to the pipeline material but preventative measures and monitoring/protective devices are necessary. These could possibly fail.	factor 10
Carrying out a suitable high-resolution metal loss In-Line Inspection (ILI) combined with thorough defect analysis and repair if necessary.	factor 10

17.4.3 *Mitigating measures to prevent external corrosion*

The measures in this paragraph have an effect on the 'external corrosion' cause of failure. The failure frequency for external corrosion can be adjusted using the following formula:

$$\text{failure frequency}_{\text{external corrosion, adjusted}} = \text{failure frequency}_{\text{external corrosion}} / \text{factor} \quad (42)$$

Only one measure can be rated.

The pipeline material is inherently totally non-corrosive in relation to the environment.	factor ∞
Carrying out a suitable high-resolution metal loss In-Line Inspection (ILI) combined with thorough defect analysis and repair if necessary.	factor 10

17.4.4 *Mitigating measures for natural causes*

The measures in this paragraph have an effect on the 'natural causes' cause of failure. The failure frequency for natural causes can be adjusted using the following formula:

$$\text{failure frequency}_{\text{natural causes, adjusted}} = \text{failure frequency}_{\text{natural causes}} / \text{factor} \quad (43)$$

Only one measure can be rated.

Impermissible ground settling and/or stresses can, to a large extent, be reasonably excluded by an evaluation.	factor 10
Natural causes can be excluded.	factor 100

17.4.5 *Mitigating measures for operational and other causes*

The measures in this paragraph have an effect on the 'operational and other' causes of failure. The failure frequency for operational and other causes of failure can be adjusted using the following formula:

$$\text{failure frequency}_{\text{operational causes, adjusted}} = \text{failure frequency}_{\text{operational causes}} / \text{factor} \quad (44)$$

Overpressure protective system based on the applicable Safety Integrity Level (SIL).

SIL used = Calculated SIL +1	factor 10
SIL used = Calculated SIL +2	factor 100

18 Technical documentation

18.1 Introduction

This chapter describes what documentation needs to be available in order to be able to assess a QRA, and specifies in detail the obligation to report a QRA.
A distinction is made between a public section and a confidential section. The PSU file that forms the basis for the calculations is confidential and may, therefore, remain within the company, but must be available to the competent authority. The competent authority requires access to this file in two situations in any case:

1. when assessing the QRA, and
2. when determining the societal risk as a result of changes in the population file.

18.2 Obligation to report a QRA to a competent authority

The items that need to be reported on in a QRA are set out in Table 19. Sensitive information may be present in the items noted as confidential. You can then weigh up whether to supply a second, public text. The second text must still be sufficient to provide third parties with the opportunity to form an opinion about the safety and risks.

Table 49 specifies the items for an independent QRA. A QRA will often be part of a more comprehensive information package. In such cases a reference to information included elsewhere in the package will, of course, be sufficient.

Table 49 Summary of the items that need to be reported on in a QRA.

	Subject	Confidential/public
1	**General report information**	
	– Administrative information: • name and address of the pipeline operator • name of the pipeline • name and address of the author of the QRA	Public
	– Reason for drawing up QRA	Public
	– Method used: • calculation package and version number	Public

	Subject	Confidential/public
2	**General description of the pipeline**	
	– Pipeline details: • name of the pipeline operator (in accordance with Bevb) • substance • diameter	Public

	Subject	Confidential/public
2	**General description of the pipeline**	
	• pressure: maximum operating pressure	
	• depth	
	• type of steel	
	• wall thickness	
	• any mitigating measures	
	• design standard including design factor	
	– Location of the pipeline, based on to-scale map(s).	Public
	• pipeline	
	• north arrow and scale indication	Public
	– Description of specific situations (pipeline strip of land, structural works, pipeline tunnels, etc.)	

	Subject	Confidential/public
3	**Description of surrounding area**	
	– Local development and designated purpose for the area	Public
	• land-use plans (partly or entirely) inside the 10^{-6} contour	
	• (moderately) sensitive objects inside the 10^{-6} contour	
	– Current topographic map.	Public
	– A description of the population around the pipeline, specifying the way in which this description has come about (including incidental development, ribbon development). A further differentiation of the details may be considered.	Public Public Public
	– Possible dangers from outside the pipeline which might have an effect on the (failure frequency of the) pipeline (neighbouring businesses/activities, flight paths, wind turbines, high-voltage pylons).	
	– Roughness length and weather station applied.	

	Subject	Confidential/public
4	**Description of possible risks to the surrounding area**	
	Summary overview of the results of the QRA which includes at least the following:	
	– Map with calculated location-specific risk, with contours for 10^{-5}, 10^{-6}, 10^{-7}	Public

	Subject	Confidential/public
4	**Description of possible risks to the surrounding area**	
	and 10^{-8} (if present).	
	– FN curve with the societal risk per pipeline for the worst case kilometre of the pipeline.	Public Public
	– Justification for the determination of the worst case kilometre.	Public
	– FN data point at which the maximum exceedance of the orientation value occurs, including the exceedance factor.	Confidential Public
	– Damage distances for weather categories F1.5 and D5 (1% and 100% probability of dying in case of exposure).	
	– Proposed preventative and repressive measures included in the QRA.	

Note:

- If there is any variation from the standard failure frequencies and/or if a scenario is modelled as a UDS model, other than as specified in the method, this must be explicitly stated.

19 Explanatory notes for Module D

This chapter includes clarification of the various chapters in Module D of the Reference Manual Bevb Risk Assessments.

19.1 Outflow scenarios (§15.1)

Leakages can occur in various ways and can therefore also vary in size. In accordance with the Purple Book a leak is modelled as an outflow from a 20 mm hole. Because most chemical product pipelines have much smaller dimensions than pipelines transporting natural gas or petroleum products, the rupture and leak scenarios differ very little from each other for a hole size of 20 mm. This is why consistency has been sought with leak scenarios for above-ground pipelines in the Reference manual Bevi Risk Assessments (HRB), which assumes a leak with an effective diameter of 10% of the nominal diameter, with a maximum of up to 20 mm.
The calculation method makes no further distinction as regards the size of the hole. The reason for this is that little information is available about hole sizes and their mutual distribution. As a result of this the failure frequency distribution cannot be determined either.

In line with Module C of the Reference Manual Bevb Risk Assessments, the leak scenario is not included for liquids that are only flammable. Nor is the leak scenario included for pipelines carrying formaldehyde solution, because this scenario is not determinative for the risk.

19.2 Scenario modelling (§15.3)

Due to the volatile nature of flammable liquids this method must also take into account effects other than pool fire. Given the fact that the Long Pipeline model cannot be used for liquids, the vessel scenario in Safeti-NL can be used. Here, rupture of a pipeline carrying flammable liquid is modelled as the instantaneous failure of a vessel at atmospheric pressure with a content equal to V_1+V_2. See section 19.6.1 for further details.

19.3 Event trees (§15.4)

Gases - Apart from natural gas only one other flammable gas is transported through pipelines, i.e. hydrogen. There is a higher probability of ignition for hydrogen due to its very low ignition energy. The literature contains extensive information about the probabilities of ignition for hydrogen, concluding that there is no clarity in relation to the probabilities of ignition and the ratio of immediate ignition to delayed ignition [13]. Given the very low ignition energy for hydrogen[15] it is assumed that in the event of a rupture or leak in a hydrogen pipeline the outflow will be sufficiently turbulent to ignite the hydrogen within the first 20 seconds after the gas escapes. This is also a safe (conservative) assumption.

[15] The ignition energy for hydrogen and methane is 0.02 mJ and 0.29 mJ respectively.

Pressurised liquefied gases – A pool fire is not included as a scenario for pressurised liquefied gases. Calculations for butane, butene and ethylene have shown that there is no rainout, meaning a pool fire will not occur.

During the development of this method the operators introduced the UKOOA method for the probability of ignition [14]. The probabilities of ignition based on this method are shown in Table 50 for a number of (realistic) pipelines. It is evident from this that the UKOOA method produces a lower result in comparison with natural gas, particularly in the case of butane, butene and vinyl chloride. This is probably due to the additional allowance of 0.1 that is used for natural gas for pipelines of up to 16 inches. In addition, the UKOOA method is based on the determination of a flammable surface and the probability of ignition is determined in combination with an assumed number of ignition sources. This method appears to be less applicable to jets because in this context ignition sources (in the surrounding area) are less important.

Table 50 Probabilities of ignition for several pressurised liquefied gases.

Substance	Flow rate (kg/s)	P (UKOOA)	P (natural gas)
Propene, 6", 40 bar	140	0.23	0.19
Butane, 4", 13.5 bar	24	0.06	0.17
Butane, 8", 40 bar	98	0.18	0.20
Butene, 6" 19 bar	65	0.13	0.18
Ethylene, 8", 100 bar	367	0.48	0.24
Vinyl chloride, 4", 64 bar	33	0.08	0.18

Based on the above a probability of ignition of 0.3 is assumed as shown in the Purple Book, where a $P_{immediate}$:$P_{delayed}$ ratio of 1:0 is used. The reason for this is that based on the calculations with Safeti-NL, it can be demonstrated that as a result of vertical outflow the plume from the pressurised liquefied gas cannot encounter any ignition sources at a height of 1 metre that could lead to delayed ignition. Calculations for vinyl chloride and propene have demonstrated that a ratio such as the one used for natural gas ($P_{immediate}$:$P_{delayed}$ is 0.75:0.25) has hardly any effect on the risk contours.
To ensure that delayed ignition does not occur as a result of the presence of ignition sources, the probability of immediate ignition parameter should be set to 1, not to 0.3. The factor 0.3 for immediate ignition must be incorporated in the probability of the event.
The Purple Book uses a lower probability of ignition for a leak, namely 0.14. This is the value used for the time being in the method for chemical product pipelines.

Liquids – As regards probabilities of ignition, consistency has been sought with the calculation method for petroleum products pipelines. For Category I liquids this method assumes a probability of ignition of 1 at a $P_{immediate}$:$P_{delayed}$ ratio of 0.065:0.935. On the other hand, the UKOOA report shows a probability of ignition of 0.07 for flammable liquids, but the $P_{immediate}$:$P_{delayed}$ ratio here can vary from 30:70 to 50:50 [14] and as a result of this there is also a possibility that no ignition occurs. It has been decided to use the conservative approach from the calculation method for petroleum products pipelines. These probabilities of ignition have also been used for the leak scenario.

19.4 Modelling gases (§15.5)

Mixing-in of air to toxic and inert gases appears to have a limited impact on the effect distances. Sensitivity calculations show that the differences in 1% lethality distance with weather type F1.5 are less than 10% (Table 51). This is why the mixing-in of air was not included for toxic and inert substances in version 2.0 of the Reference Manual.

Table 51 Addition of air and outflow speeds for various toxic gases.*

	Release rate (kg/s)	Discharge velocity (m/s)	Pre-dilution air rate (kg/s)	1% lethality F1.5 (m)
CO (70 bar 168 mm)	155	500	0	26
	155	100	50	28
HCl (25 bar 219 mm)	125	440	0	39
	125	100	50	42
N_2 (64 bar, 324 mm)	740	500	0	0
	740	100	100	0
Cl_2 (22 bar, 104 mm)	40	65	0	3600
	40	10	10	3400

- Release rate and discharge velocity apply to the first segment when using time-varying release.

Modelling hydrogen

In the case of a rupture, the outflow of gas from underground pipelines is accompanied by the formation of a crater. As a result of this, an additional quantity of air is mixed in with the gas flowing out. The entrained air considerably reduces the release velocity, in comparison with a release from an above-ground pipeline, and decreases the concentration more rapidly. This has an impact on the size and the orientation of the jet fire and therefore on the effect distances. Safeti-NL version 6.54 did not take into account the air entrainment resulting from a crater. Therefore for hydrogen a UDS scenario was used where values for air entrainment and (reduced) discharge velocity had to be entered manually. In Safeti-NL version 8, a crater model has been included. This model directly calculates the air entrainment and the (reduced) release velocity.

For the location of the leak, the option 'puncture at the top' has been selected. The estimation is that the failure cause 'external damage' is more likely to lead to a leak at the top of the pipeline, while other failure causes are uniformly distributed.

Safeti-NL
Since the flame from hydrogen does not produce soot, the heat transfer is smaller than for most other flammable substances, which do produce soot. As a result, hydrogen flames are generally hotter than other flames. This is why Safeti-NL would produce an overestimate of the effects for hydrogen. However, the heat transfer for large hydrogen jet fires has proven to be comparable with substances like propane and methane due to the presence of water in the jet fires [15]. This still ensures considerable thermal radiation, as a result of which there is no need to adjust the modelling in Safeti-NL.

19.5 Modelling pressurised liquefied gases (§15.6)

Just as for gases, the outflow of a pressurised liquefied gas from underground pipelines in the event of rupture is accompanied by the formation of a crater and a vertical outflow of the pressurised liquefied gas. Safeti-NL version 6.54 did not take into account entrainment of air as a result of the crater. The extent to which air is mixed in the crater when pressurised liquefied gases are released was not known. During flashing of pressurised liquefied gas the substance expands very significantly and the expectation was that, as a result of the expanding movement, no additional air would be supplied in the crater. This is why mixing in of air and decreased outflow speed were not taken into account in version 2.0 of the Reference Manual for a rupture of an underground pipeline with pressurised liquefied gas.
In Safeti-NL version 8, a crater model has been included, enabling the model to calculate the air entrainment and the (reduced) discharge velocity. With this crater model, the risks of underground pipelines can be better mapped out. RIVM has carried out an exploratory study into the possible consequences of prescribing the updated version of Safeti-NL. It shows that applying the crater model to hazardous substances other than natural gas and hydrogen leads to considerably larger risk contours and areas of interest or attention areas. According to Article 19 of the Bevb, the incorporation of existing pipelines into zoning plans has been realised by 1 July 2019. Based on the insights at the time, this zoning plan only takes into account a crater effect for natural gas and hydrogen. In the interest of legal certainty and in view of the estimated new insights into the crater effect for hazardous substances other than natural gas or hydrogen, the Ministry of I&W does not consider it desirable to prescribe the use of the crater model for hazardous substances other than natural gas and hydrogen. For this reason, the Ministry of I&W has decided for the time being not to prescribe the crater model for substances other than natural gas and hydrogen. However, the crater model can be used for precautionary purposes.

The critical temperature and pressure for ethylene are 9.19ºC and 50.4 bar(a) respectively. The liquid phase in the transport pipeline is when the temperature is lower than 9.19 ºC and the supercritical phase is when the temperature is higher than 9.19 ºC. Safeti-NL uses the PIPEBREAK model for the liquid phase and the GASPIPE model for the supercritical phase.

Table 52 Ethylene: PIPEBREAK vs GASPIPE[16].

	Outflow time (s)	Flow rate (kg/s)	1% lethal m (jet fire)
PIPE-BREAK	0	2700	248
(T = 9 ºC)	60	260	100
	600	130	79
GASPIPE	0	3460	250
(T = 10 ºC)	60	300	105
	600	135	73

Modelling the outflow near the supercritical point is difficult because the liquid, gas and supercritical phases can occur alongside each other meaning the expansion zone is not homogeneous. Exploratory calculations have been performed to investigate the differences between PIPEBREAK and GASPIPE. It turned out that the two models produce similar effects distances (see Table 52), and it has been decided to use the PIPEBREAK model due to the greater modelling robustness.

19.6 Modelling liquids (§15.7)

Substances that are liquid at atmospheric pressure and room temperature cannot be calculated using the Long Pipeline model in Safeti-NL. The Line Rupture model is not suitable and not meant for transport pipelines which means that an alternative model is needed for pipelines transporting liquids. We have tried to stick as closely as possible to the method for petroleum products pipelines (Module C).
The leak scenario has not been included for liquids that are only flammable or only toxic. See section 19.1

19.6.1 Flammable liquid (§15.7.1)

The rupture of an underground pipeline will produce a fountain of liquid (Module C), but this is of short duration because the pressure in the pipeline will drop quickly. The large majority of the liquid that is released will end up on the ground and a small proportion will evaporate before it reaches the ground. In the case of immediate ignition of a flammable liquid there will therefore be a flash fire together with a pool fire, while in the case of delayed ignition there will only be a pool fire. When the liquid is both flammable and toxic, there will be evaporation of the pool in the absence of immediate ignition.
Both effects (flash fire + pool fire or flash fire + evaporation of the pool) can be entered using one scenario in Safeti-NL, i.e. the instantaneous failure scenario that is normally used for storage tanks. The pressure to be used is atmospheric pressure or a very low overpressure. This guarantees that the pool is formed near the pipeline and not dozens of metres away. First, the amount of liquid that has flowed out of pipeline is determined and used as the contents of the 'tank' at atmospheric pressure. In instantaneous failure the liquid flows out forcefully into a bund. The size of this bund matches the surface area of the pool that is formed. The force of the outflow will cause a part of the liquid to evapo-

[16] LP model, pipeline 98 bar and 10", length 50 km, outflow at 'rate at given time', D5.

rate and produce a flash fire in the event of immediate ignition. If immediate ignition does not occur, Safeti-NL calculates either the pool fire or the evaporation of the pool, depending on the hazard characteristics of the liquid.

The shut-down time or shut-down time for the pump is determined by the time that is needed until the pump shuts down automatically (as a result of pressure loss), by how long detection takes or – if intervention by an operator is needed – by the operator's reaction time added to the time required to close a valve in the transport pipeline. The pump shut-down time must be substantiated by the user.

Because there are no details about the compressibility of the liquids involved, the compressibility used in Module C is applied [16].

A pool will be formed as a result of a rupture of an underground pipeline carrying liquid. In rural areas the ground onto which the outflow will take place is different to that in a built-up area. However, effect calculations have demonstrated that the substrate onto which the outflow takes place has almost no impact on the calculated lethal effect distances.

In the case of liquids, the surface area of the pool that is formed is an important factor. The size of the pool is determined by a number of parameters, such as the source strength and the substrate. The method for petroleum products and flammable liquids pipelines assumes a pool depth of 0.05 m (Module C). This depth is also used for chemical product pipelines. The size of the pool can then be determined from the released volume and this pool depth.

19.6.2 *Flammable and toxic liquid - rupture (§15.7.2)*

Ethylene oxide (EO) has a boiling point of 10.7 ºC. As the model uses a temperature of 9.8 ºC EO is considered to be liquid by default. However, given the boiling point of 10.7 ºC research has been carried out into the risks of EO as a pressurised liquefied gas at a temperature of 12 ºC. When EO is modelled as a liquid (section 15.7.2) the risk is strongly dominated by the leak scenario. In the event of immediate ignition, the rupture scenario produces a flash fire and a pool fire, the effects of which are limited to the immediate vicinity of the pool. In the absence of immediate ignition, Safeti-NL will consider the evaporation from the pool. Because this concerns passive distribution, the toxic effects in the rupture scenario are relatively limited. In contrast, in the leak scenario the liquid droplets are released at high velocity. In the absence of immediate ignition, the toxic effects of the leak scenario extend further than in the rupture scenario, because the initial cloud is already large at the start.
When EO is modelled as a pressurised liquefied gas the standard modelling using the Long Pipeline model can be used for the rupture scenario. To maintain consistency with the probabilities of ignition for pressurised liquefied gases, the corresponding probabilities of ignition have been used for EO[17].

[17] The higher probabilities of ignition are justified because EO is a highly reactive substance (large explosion area (3-100%) that requires little ignition energy (☐ 0.06 mJ)).

The results of the exploratory calculations are shown in Table 53. Modelling EO as a pressurised liquefied gas produces larger IR 10^{-6} contours and leads to a greater proportion of the rupture scenario. Because modelling EO as a pressurised liquefied gas is simpler and more robust it has been decided to model EO in this way.

Table 53 Results of exploratory calculations for an EO pipe (15 bar, 8").

$P_{immediate}$	IR × 10^{-6} (m)	IR_{max}	% rupture
Modelled as a liquid			
0.065	345	5.0 × 10^{-6}	2
Modelled as a pressurised liquefied gas			
0.065	425	8.5 × 10^{-6}	48
0.3	405	7.7 × 10^{-6}	45

19.6.3 *Toxic liquid (§15.7.4)*

The amount of formaldehyde that evaporates from a watery pool depends in part on the wind speed. The higher the wind speed, the greater the amount of formaldehyde that will evaporate. It has been decided to use a wind speed of 5 m/s because this speed is the most common in the Netherlands (weather types D5 and E5).

19.7 Societal risk (§15.8)

The author of a QRA must show the maximum (exceedance) factor for the orientation value for the worst case kilometre and the number of victims N at which this maximum occurs. This can be determined as follows:

1. In SAFETI-NL, a 'Smoothed FN' must be selected for a study with valid results via the Risk tab > under Societal Risk (SR) graphs.
2. In the graph, the data of the FN curve can be obtained by right-clicking with the mouse. This data is then displayed in a table, which can be exported to excel using Grid > General > Export To Excel.
3. The ratio between the frequency of the FN point and the frequency of the orientation value for this N must be calculated per N (from N-10). The maximum possible exceedance and the corresponding number of victims must be reported.

19.8 QRA-specific parameters (§16.2)

19.8.1 *Settings to be used by default (§16.2.1)*

The standard outflow direction for underground pipelines is vertical. It is as-sumed that after a rupture or leak the two horizontal jets from each half of the pipeline will be fully in contact with each other after which outflow takes place in a vertical direction.
An outflow height of 0.01 cm instead of 0 m has no effect on the results, but will in a limited number of cases prevent error messages or unrealistic results.
The roughness length of a surface is an (artificial) measurement of length that indicates the effect of the surrounding area on wind speed. The roughness length used for determining the wind profile is 0.1 metres by default and applies to an environment with low vegetation and

scattered large obstacles (x/h>20). Here x is the typical distance between obstacles upwind and h is the typical height of the obstacles.

19.8.2 Time-varying release (§16.2.3)

In Safeti-NL it is possible to select a flow rate at a particular time, a flow rate averaged over a specific time window, and a time-varying release. In the case of the latter, the outflow is divided into a number of time segments with equal mass, and an average flow rate is calculated for each segment.
The outflow for transport pipelines carrying hazardous substances can be modelled as a time-varying release with (for example) ten segments. The total duration of interest here must not be longer than 1800 seconds.

19.8.3 Modelling people for events (§16.2.6)

An example of how the population can be modelled for events:
The area surrounding an establishment contains a housing estate and a recreational lake. Over the three summer months an average of 200 people are present at the lake during an eight-hour period in the daytime; at night and outside the summer months there are virtually no visitors.
In Safeti-NL this is modelled by working on the basis of three rows:

- One day row with a factor of 0.08. The population present is the housing estate (daytime) and the people using the recreational facilities.
- One day row with a factor of 0.36. The population present is the housing estate (daytime).
- One night row with a factor of 0.56. The population present is the housing estate (night time).

The factor of 0.08 for the day row is calculated from the period that the people are present at the recreational lake, i.e. three months per annum (3/12) and eight hours per day (8/24).

19.9 Parameters specific to a QRA in the Netherlands (§16.3)

19.9.1 Duration (§16.3.1)

A different outflow duration and amount can be applied if it can be demonstrated that the duration of the outflow from an underground pipeline through which toxic substances are transported is shorter than 30 minutes as a result of the safety devices installed. Here account must be taken of the length of time before the rupture is detected by the relevant devices present (if any), the response time of an operator (if applicable) and the time that it takes any valves etc. to close (including subsequent delivery from the isolated pipeline).
A different outflow duration has no effect in the case of pipelines through which flammable (pressurised liquefied) gases are transported because only the average source strength over the first 20 seconds is relevant for this category.

19.9.2 Lethality and probits (§16.3.3)

The values for a, b and n (mg/m^3 and minutes units) have been taken from the Reference Manual Bevi Risk Assessments [2]. The Safeti-NL calculation package uses the ppm and minutes units for its calculations.

Consequently, the values for a, b and n are also given in the ppm and minutes units. These are calculated using the following formula:

$$a_{ppm} = a_{mg/m^3} + b \times \ln\left(\frac{M}{22.4 \times \frac{282}{273}}\right)^n \quad (45)$$

where M is the molar mass (in g/mol).

19.9.3 *Substance-specific parameters (§16.4)*

An unequivocal probit relationship is not available for carbon dioxide. The rea-sons for this are described in [17]. This table does contain semi-quantitative estimates which can be used as the basis for deriving a probit.

20 Appendix - Preconditions for reduction factors

A reduction factor associated with a measure can only be used if the measure complies with the preconditions that are applicable to it. This chapter describes those preconditions. These are based on reference 7 and updated to NEN3655. The basic principle is that the pipeline for petroleum products complies with the state-of-the-art. The preconditions applicable to this are described first.

Preconditions for state-of-the-art pipelines.

The most important condition for being allowed to apply the failure frequency for the rupture scenario for a state-of-the-art pipeline is the use of an effective safety management system (SMS) in accordance with Section 4(1) of the External Safety of Pipelines Decree (Bevb). The state-of-the-art conditions for the various causes of failure are set out in Table 54. If one of the corresponding conditions is not met for a specific cause of failure, the appropriate failure frequency mentioned in Table 4 should be used for this cause of failure.

Table 54 Preconditions for state-of-the-art pipelines.

General	The use of an effective safety management system in accordance with Section 4(1) of the External Safety of Pipelines Decree (Bevb) and NEN3655.
Damage by third parties	• Clearly indicated above-ground markers for the pipeline that can be seen from every angle. You may deviate from this rule for practical limitations such as bends, thickets and obstacles. • Periodic communication with land owners to make and keep them aware of the presence of the pipeline. • Implemented KLIC [*Cables and Pipeline Information Centre*] /WIBON system with active reminder.
Mechanical	• Pipelines laid before 1980: having a mechanical assessment of the pipeline available. • Pipelines laid in or after 1980: none; are covered by significantly improved quality assurance and quality control (QA/QC) during pipeline construction.
Internal corrosion	Corrosion management system comprising: • determination of product corrosiveness; • use of design measures based on corrosiveness (for example, corrosion addition to wall thickness, use of corrosion inhibition, use of corrosion-resistant steel alloys for the pipe wall and, if necessary, internal coating/liner); • effective monitoring programme (for example, monitoring product quality by sampling, injecting chemicals, sampling for release of metals).
External corrosion	Use of suitable coating and cathodic protection in accordance with NEN 3654. Effective monitoring

	programme for cathodic protection of the coating.
Natural causes	The structural design in relation to ground settling and stresses is known and documented and suitable measures have been taken.
Operational and other causes of failure	• Specified operating range in relation to flow rate, pressure, temperature, trip settings. • Automatic process monitoring and process safety devices. • Monitoring of all relevant DCS or SCADA data to continue operating within this operating range. • Changes to the operating range are only permitted using specified procedures, such as for modifications (Management of Change, MoC).

Preconditions for 'excavation damage by third parties'

A number of measures with corresponding reduction factors have been formulated for the excavation damage by third parties cause of failure. This para-graph sets out the preconditions for the various measures.

Cluster 1

Active reminder

- The operator should contact the excavation contractor within ten working days of the notification if they have not already done so.

Cluster 2

This relates to the warning tape, protection plates and the combination of warning tape + protection plates measures.

- The minimum distance between a pipeline and the protective material and the width of the cover must be recorded in a standard document. The combination of the two factors (protective material and the distance between the material and the pipeline) must be such that the cover is effective and there is no contact with the pipeline even when employing the largest excavators that are in use at that time.
- The strength and suitability of the different materials and structures should be demonstrated by field testing. The basic principle is that field testing is carried out in the same way as the field testing that was carried out to determine the reduction factor for protection plates [18]. The reduction factor can be derived in the same way[18].
- If the cover on one pipeline also covers other pipelines, the other operators will have to be consulted in this case.
- These measures can only be used if the pipeline operator grants per-mission for taking them. It is primarily the effect of the cathodic protection and, for instance, accessibility for coating inspections that are important in the considerations.

[18] If the measure proves to be effective in all experiments, to derive the reduction factor it must be assumed that the measure was not effective for one experiment. This assumption is nec-essary because with a limited number of tests (n) it is not possible to rule out the (n+1)th test re-sulting in failure.

Cluster 3

This relates to measures where a management agreement with a specific effect has been concluded.

Agreement with extensive restrictions:

- The land is taken out of use through leasing or a strict management agreement that excludes all use of the land.
- The relevant part of the land is fenced off.
- Markers are used.
- The land owner must be contacted periodically (at least once each year) to discuss the situation concerned.
- During the (helicopter) inspections the pipeline section to which the agreement applies must be given specific attention.
- It must be possible to reject and never accept any request for excavation work by the owner and third parties. Action must be taken immediately upon receipt of a notification. It must be immediately clear to those handling the notification that a management agreement applies to the pipeline section concerned.
- If an agreement does not comply with all of the preconditions the agreement will deliver, at the very most, the reduction factor for an agreement where digging/drilling is prohibited (see the 'Digging/drilling prohibited agreement' measure).

Digging/drilling prohibited agreement:

- Using the land as a pasture, for instance, is permitted with an agreement where excavation work is excluded. Use as a parking or storage site, for instance, is also possible, provided that no excavation work is needed to realise this.
- The land owner must be contacted periodically (at least once each year) to discuss the situation concerned.
- During the (helicopter) inspections the pipeline section to which the agreement applies must be given specific attention.
- It must be possible to reject and never accept any requests for excavation work by third parties. Action must be taken immediately upon receipt of a notification of excavation work. It must be immediately clear to those handling the notification that a management agreement applies to the pipeline section concerned.
- If an agreement does not comply with all of the preconditions the agreement will deliver, at the very most, the reduction factor for an agreement with limited restrictions (see the 'Limited restrictions agreement').

Limited restrictions agreement:

- In an agreement with limited restrictions, excavation work is not totally excluded but limitations apply to the work in relation to the depth of working the land.
- The land owner must be contacted periodically (at least once each year) to discuss the situation concerned.
- During the (helicopter) inspections the pipeline section to which the agreement applies must be given specific attention.

Cluster 4

Fencing

- A fence must prevent entry into the immediate vicinity of the pipeline. If fencing only encloses the area near to the pipeline but the area can easily be entered otherwise, fencing must be considered to be marking.
- This measure must be used in combination with marking.
- Accessibility of the pipeline must not be impeded.

Embankment

- The embankment relative to ground level is at least one metre high and this height must be maintained. Alternatively, an embankment with a height of 50 cm can be created. However, in this case (metal) netting that provides sufficient resistance if digging were still to take place must enclose the embankment.
- The embankment must be uninterrupted over the part of the pipeline for which the measure is applied. Because it cannot be ruled out that roads will have to be crossed etc., the guideline is that at least 98% of the part of the pipeline concerned must be protected by an embankment. If less than 98% of the relevant part of the pipeline is protected, a QRA must take specific account of the interruptions. The part that is not protected by an embankment must be protected in another way, by road paving for instance. In addition, additional marking must be placed at the start and end of the interruption.
- The measure must be used in combination with markings.
- The embankment must not have any impact on the integrity of the pipeline.
- Accessibility of the pipeline must not be impeded.

Ground-level barrier

- The distance between the barrier and the pipeline must be limited to one to two metres.
- Free-standing posts must be positioned a maximum of 20 cm apart.
- This measure must be used in combination with marking.
- Accessibility of the pipeline must not be impeded.

Cluster 5

Strict supervision of activities

- In the event of a notification, the pipeline operator must immediately contact the contractor performing the activities. Working agreements, which are recorded in writing, are to be made during this contact. The pipeline operator must check the situation in situ daily until the time that contact is established with the contractor.
- If there is more than one week between the notification and the start of the activities, the pipeline operator must contact the contractor performing the activities every week (until the start of the activities).
- If the activities last longer than one week, the pipeline operator must carry out an additional in situ inspection every week (until the activities have been completed).

- Additional marking is to be used during the activities.
- It must be immediately clear to the pipeline operators staff handling the notification that strict supervision applies to the pipeline section concerned. This is to be guaranteed in the procedure for dealing with notifications.

Camera monitoring
- Monitoring must be continuous.
- It must be possible to monitor the entire part of the pipeline to which the reduction factor is applied.
- If (preparations for) activities near the pipeline are detected, it must be possible to intervene to halt those activities within minutes.
- Notified activities must be fed back to the individual doing the monitoring to prevent false alarms.

Cluster 6

A precondition for this measure is that the cover must be effective on both sides of the pipeline. The cover must be applied in such a way that it can be expected that an excavating contractor who digs at right angles to the pipeline continues to follow ground level and will not ignore the additional cover by following the level at excavation depth. The guideline for additional ground cover up to 20 cm is that the additional cover must be applied over a minimum of 10 metres on either side of the pipeline. For additional ground cover in excess of 20 centimetres the additional cover must be applied over a minimum of the strip of land affected.

'In-line inspection (ILI)' preconditions

ILI measurement performance must comply with the following requirements:
1. The probability of detection of potentially critical defects is at least 90%.
2. Material loss detection threshold 10% (overall wall thickness) and 15% (pitting) for Magnetic Flux Leakage (MFL) and 1.5 mm for Ultrasound Testing (UT).
3. Detection of defects of a surface of 20 x 20 mm or more.
4. ILI must be capable of identifying dents deeper than 2% of the internal diameter.

The inspection interval must be based on a thorough and standardised risk analysis with a fit-for-purpose (FFP) demonstration. The maximum ILI interval is ten years.

Additional measures in relation to general standards and procedures have been drawn up for evaluating ILI as a measure.

General

Which industry standard is applied for using ILI depends on various considerations, as long as a) they are aimed at preventing failure of a pipeline as a result of, for instance, internal and/or external corrosion, and b) the 'Fitness for Purpose' (FFP) and/or 'Fit for Service' (FFS) is confirmed in accordance with industrial Integrity Management (IM) principles. The operator should be able to demonstrate what is done to any defects that are observed and what considerations are used when doing so. Relevant features should be repaired timely and the repairs should be properly documented. A thorough effect analysis follows the same method as a thorough risk analysis.

Available standards
There should be consistency with 'Specifications and requirements for intelligent pig inspection of pipelines, 2009 Version, Appendix I' (see below) and the upper limits contained therein.
Operators using the reduction factors for ILI must have suitable procedures for the ILI/FFP/FFS/RBI/IM implementation process and acceptance criteria for anomalies that are detected ('features'). In the case of ILI, this involves consistency with recent specifications such as those formulated by the POF (Pipeline Operator Forum):

1. Specifications and requirements for intelligent pig inspection of pipelines: 2009 version.
2. Guidance documents to achieve In-Line-Inspection first run success:
    - Guidance on achieving ILI First Run Success, December 2012,
    - ILI Pipeline Questionnaire, December 2012,
    - ILI Check Lists, December 2012,
    - ILI Data Feedback Form, December 2012,
    - Guidance on Field Verification Procedures for In-Line-Inspection, December 2012,
    - ILI Field Verification Form, December 2012.

The following codes or guidelines can be used as reference for the standards for fitness-for-purpose analysis (FFP).

- NEN-3650:2012 Chapter 10. Requirements for pipeline systems.
- NEN 3655: safety management system (SMS) for pipeline systems for the transport of hazardous substances, 2020.
- API 579 -1 / ASME FFS-1. Recommended Practices for Fitness for Service.
- API 1160. Managing System Integrity for Hazardous Liquid Pipelines,
- ASME B31G. Manual for Determining the Remaining Strength of Corroded Pipelines.
- ASME 9909A-RPT-001. Pipeline Defect Assessment Manual.
- API 7910. Guide to methods for assessing the acceptability of flaws in metallic structures.
- PD 8010-4:2012. Pipeline systems. Steel pipelines on land and subsea pipelines. Code of practice for integrity management.
- Assessment of the Integrity of Structures Containing Defects, British Energy Generation, Report R/H/R6, Nuclear Electric.
- SINTAP. Fitness Structural INTegrity Assessment Procedures for European Industry,
- DNV-RP-F116. Integrity Management Systems of submarine pipeline systems, 2009,

The following standards, among others, can be used as reference specifically for the evaluation of corrosion defects using ILI:

- ASME B31G + Modified B31G. Method for strength calculations/remaining service life calculations.
- RSTRENG. Computer program for calculating pipe corrosion.
- DNV-RP-F101. Corroded Pipelines · Pipeline Field Joint Coating and Field Repair of Linepipe Coating, 2010.

For a transparent working method and evaluation of the reduction factors it is appropriate that the sector develops a complete guideline for the entire process based on existing standards.

NB. There are a number of 'non-piggable' pipelines which by their very nature means that ILI cannot be used. There have, however, been developments where the integrity status can be determined indirectly using existing techniques (CIPS/DCVG) and new analysis and evaluation techniques. With substantiation from the sector such evaluation techniques could become eligible for consideration.

RBI option
The operator must demonstrate that the integrity of their pipeline is guaranteed. To do this they could opt for the RBI (Risk Based Inspection) approach. To this end, the way in which the RBI is set up must be documented. If any defects are detected, a thorough analysis must lead to hypotheses on the possible causes. The fault/failure hypotheses must be linked to the consequences for the integrity and use of the pipeline (e.g. duration, conditions). This determines the inspection regime and the actions arising from that regime (e.g. use restrictions, measurement frequency, monitoring the quality of the medium, etc.).

Elements that should form the basis of an RBI approach:

1. Formulating performance requirements and criteria, planning and selection tool;
2. Collection and integration of data: intended to facilitate a risk management approach. Data and an evaluation of the first pig run must already be available, and no changes have occurred in operational management or conditions (MoC);
3. The subdivision of the pipeline (or pipeline network) into sections: the pipeline system is divided into sections where threats or consequences differ from the threats or consequences in other sections;
4. Identification of threats: the dangers that could result in a rupture, leak or interruption of supply have been identified. All features are analysed;
5. Risk analysis: the probability of failure as a result of a threat and the con-sequences of this failure are evaluated and multiplied and form a risk for each threat (and section);
6. Risk evaluation: the calculated risk is compared with an accepted risk level for a threat/section/pipeline;
7. Mitigation: a plan has been drawn up to manage the risks, linked to the relevant threats. All features are documented;
8. Evaluation and improvement: the process is continuous and is part of an improvement cycle.

'Internal corrosion - corrosiveness of the medium' preconditions

The corrosiveness must be substantiated and the quality of the medium should be monitored. A substantiation of 'inherently non-corrosive medium' and/or 'inherently non-corrosive pipe material' must be included in the report.

'External corrosion - corrosiveness of the pipe material' preconditions

The lack of corrosiveness should be substantiated and the environment (acidification, bacteria, roots, excavation work, interference) should be monitored.
Inclusion of substantiation of 'inherently non-corrosive pipe material' in the report is required.

'Natural causes' preconditions

Impermissible ground settling/stresses can be excluded to a large extent
Impermissible ground settling and/or stresses can be excluded to a reasonably large extent by means of an evaluation:

- By checking the soil conditions, by inventorying critical areas (e.g. mining, structural works, peatlands);
- By creating a controlled situation in critical areas, for example measuring/calculating stresses, measuring using settlement gauges / settlement rods, design with strain gauges, foundations, over-dimensioning of the structural design, lack of joins and other fittings, stress-free position.

Reports on the evaluation should be available within one year from claiming the reduction factor.

Natural causes can be excluded
Natural causes can be excluded when a substantiated report provides evidence of a solid and stable surface (sandy soils for example).

- By checking the soil conditions on the basis of which critical areas can be excluded (e.g. stable clay, sand).
- Impermissible ground settling and/or stresses are demonstrably excluded (e.g. based on case studies over many years).

'Operational and other failure' preconditions

1. Implementation of an overpressure protection system based on the applicable Safety Integrity Level (SIL) in accordance with IEC 61511 which has been derived from a hazard assessment of failure mechanisms including pressure/temperature relief, and:
2. implementation of a test regime for the overpressure protection system and proper training for the operators in operating the system, and:
3. ensuring that the operating envelope for the pipe is not exceeded.

Preconditions: proper commissioning with hydro-testing on taking into use, if possible, and periodical functional testing (part of SIL).

NB. although underpressure protection does not form part of the effort to limit the probability of failure per se, it is expected that the SIL level for this protection corresponds with the overpressure protection.

21 References for Module D

[1] Committee for the Prevention of Disasters (CPR), *Guidelines for quantitative risk assessment ('Purple Book'),* PGS18 (1999).
[2] RIVM, *Reference Manual Bevb Risk Assessments*, version 4 (2019).
[3] Det Norske Veritas (DNV), the Dutch version of *Software for the Assessment of flammable, explosive and toxic impact* (Safeti-NL) version 6.54 (2009).
[4] *Regeling externe veiligheid buisleidingen* [External Safety Pipelines Order], Section 6(2).
[5] Descriptions of the models can be found in the Technical Documentation that comes with the software.
[6] *Register risicosituaties gevaarlijke stoffen* [Risk Situations (Hazardous Substances) Register] (RRGS), situation as at March 2010.
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