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Guidelines for quantitative risk assessment

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Guidelines for quantitative risk assessment

Ministerie van **Binnenlandse Zaken** *en* **Koninkrijksrelaties**

SZW

Ministerie van Verkeer en Waterstaat

PREAMBLE

Starting from June 1st 2004, the Advisory Council on Dangerous Substances (Adviesraad Gevaarlijke Stoffen - AGS) was installed by the Cabinet. At the same time the Committee for the Prevention of Disasters (Commissie voor de Preventie van Rampen-CPR) was abolished.

CPR issued several publications, the so-called CPR-guidelines (CPR-richtlijnen), that are often used in environmental permits, based on the Environmental Protection Law, and in the fields of of labour safety, transport safety and fire safety.

The CPR-guidelines have been transformed into the Publication Series on Dangerous Substances (Publicatiereeks Gevaarlijke Stoffen – PGS). The aim of these publications is generally the same as that of the CPR-guidelines. All CPR-guidelines have been reviewed, taking into account the following questions:

1. Is there still a reason for existence for the guideline or can the guideline be abolished;
2. Can the guideline be reintroduced without changes or does it need to be updated.

This PGS 3 edition of the guidelines for quantitative risk assessment hasn't been changed in regard of the first 1999 edition.

Also on behalf of my colleagues at the Ministries of Transport, Social Affairs and of the Interior,
The State Secretary of Housing Spatial Planning and the Environment (VROM).

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December 2005

Guideline for quantitative risk assessment

'Purple book'

CPR 18E

Part one: Establishments

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PREFACE

This report documents the methods to calculate the risks due to dangerous substances in the Netherlands using the models and data available. Calculation of the risks relates, on the one hand, to stationary installations and, on the other, to transport and related activities.

The report consists of two parts. Part 1, describing the methods to calculate the risks of stationary installations, was written by the National Institute of Public Health and the Environment (RIVM) under a supervisory committee of representatives from the subcommission on Risk Evaluation of the Committee for the Prevention of Disasters (CPR-RE). Part 2, drawn up under the responsibility of the Ministry of Transport, Public Works and Water Management, describes the calculation of the risks connected with the transport of dangerous goods, based on the approach developed in accordance with the Ministry of Housing, Spatial Planning and the Environment and set down in the last few years in various commissions.

Although the report describes the present-day calculation methods (in practice, no better methods are currently available), discussions on a number of subjects in the supervisory committee led to the conclusion that additional research would be necessary to guarantee the quality of the calculation methods in the future. Three subjects for study were indicated:

A. The failure frequencies of stationary installations. Failure frequencies are based on the so-called COVO study from 1981. Additional failure frequencies have been determined in various studies carried out for the Dutch government over the years. Recently, new studies have been published, reporting different figures - mostly higher - for a number of failure frequencies. A more detailed study on the failure frequencies will be carried out, concentrating especially on the original data sources.

B. The meteorological model. Dispersion calculations are carried out as part of the risk analyses using generally accepted meteorological models and the corresponding meteorological data. The national model used in air pollution calculations has recently been adapted to include new insights. At the moment, meteorological statistics are not sufficiently available to apply this new meteorological model to risk analyses. The relevance of the new model to risk analyses should be ascertained; furthermore, the consequences which the new model, including the model parameters, could have on the results of calculating risks should be examined. The study on these consequences will be started up in the short term.

C. Differences in risk calculations for transport and for stationary installations. The method to calculate the risks of transporting dangerous goods is comparable to the calculation method applied to stationary installations. During the last few years, the basic principles of risk analysis have been discussed and established with the parties involved. Since developments in the risk calculation methods for transport and stationary installations were separate, several differences exist between the basic principles in risk calculations for transport and for stationary installations. These differences relate, among other aspects, to the frequency of catastrophic failure of tank wagons relative to stationary tanks and to certain loss of containment scenarios.

The Committee for the Prevention of Disasters considers it important to have reliable risk calculations for stationary installations and for transport of dangerous goods; these should, as far as possible, also be founded on similar basic principles. It is therefore advisable to analyse the basic principles of the calculation methods and to study the consequences of removing the differences in the calculation methods. Both the Ministries mentioned above can then decide whether these differences should actually be reduced.

The discussions show that the methods of risk analysis are still being further developed. The Committee for the Prevention of Disasters is pleased that with the publication of this report a substantial contribution will be made to the further development of this risk analysis instrument. The Committee thanks the government experts, research institutes and industry for their contributions. The Committee for the Prevention of Disasters is convinced that the report will be of great value for all those dealing with risk analysis and risk management.

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1. INTRODUCTION

A Quantitative Risk Assessment (QRA) is a valuable tool for determining the risk of the use, handling, transport and storage of dangerous substances. QRAs are used to demonstrate the risk caused by the activity and to provide the competent authorities with relevant information to enable decisions on the acceptability of risk related to developments on site, or around the establishment or transport route.

If the results of a QRA in the decision-making process are to be used, they must be verifiable, reproducible and comparable. These requirements necessitate QRAs made on the basis of similar starting-points, models and basic data. Ideally, differences in QRA results should only arise from differences in process- and site-specific information. A number of documents for attaining comparability in the QRA calculations have been published over the years. The Committee for the Prevention of Disasters (CPR) has issued three reports describing the methods to be used in a QRA calculation, namely the ‘Red Book’, the ‘Yellow Book’ and the ‘Green Book’. The ‘Red Book’, describing the methods for determining and processing probabilities, is to be used to derive scenarios leading to a loss of containment event [CPR12E]. The ‘Yellow Book’ describes the models to determine the outflow and dispersion of dangerous substances in the environment [CPR14, CPR14E], and finally, the ‘Green Book’ describes the impact on humans of exposure to toxic substances , heat radiation and overpressure [CPR16].

All three books provide the scientific information to be used in a QRA on the basis of present-day knowledge. However, this information is not sufficient to carry out a complete QRA calculation. Additional information is needed, for example, information related to policy decisions and data for which adequate scientific knowledge is not available (yet). Usually, standard values for this type of data are set by consensus following discussions between representatives from industry, the competent authorities and the central government. The outcome of these discussions has been published in a number of documents (e.g.[KO 9, KO 12, KO 20-2, KO 24-2, IPO]). However, the large collection of documents issued over the years, with documents sometimes superseding one another, has called up a need to merge them all into one report, making use of experiences gathered in conducting QRA analyses. The outcome then is this report, ‘Guideline for Quantitative Risk Assessment’, in which all necessary starting-points and data needed to perform a QRA calculation are recorded.

The report is organized in the same way that a QRA calculation is performed, i.e. starting with the selection of installations and the definition of loss of containment events, followed by dispersion and effect calculations, and the presentation of the results.

The selection of installations is described in Chapter 2. Since the total number of installations in an establishment can be very large and not all installations contribute significantly to the risk, it is not worthwhile to include all installations in the QRA. Therefore a selection method is given to indicate the installations that contribute most to the risk.

The loss of containment events are defined in Chapter 3. Generic loss of containment events and failure frequencies are defined for a number of standard installations like storage tanks, transport units, pipelines and loading equipment. Normally, generic values should be used in the QRA calculation; however, it is possible to use site-specific information so as to modify loss of containment events and failure frequencies.

Although models to calculate the outflow and the dispersion of dangerous substances are extensively described in the ‘Yellow Book’ [CPR14E], a number of topics are not covered, like the influence of repression systems on the outflow and the dispersion of dangerous substances, time-varying releases and the ignition of flammable clouds. A need for standard values for the location and direction of the release and for meteorological parameters is also felt. These and other model aspects are therefore investigated in Chapter 4.

The effects of toxic substances, fires and explosions on humans are described in Chapter 5. The information in this chapter is largely based on the ‘Green Book’ [CPR16]. However, Chapter 5 also describes how the protection of people staying indoors should be accounted for in the QRA calculation. Furthermore, some guidance is given on surveying a population near the activity involving dangerous substances.

To illustrate the computation of both the individual and societal risks, a calculation method is outlined in Chapter 6. This chapter is intended to demonstrate the principles of a QRA calculation; it does not give a complete description of an established set of calculation rules. Guidelines on the presentation of the individual and societal risks are also given.

Finally, Chapters 7 - 9 cover several aspects related to a QRA study. Chapter 7 focuses on the environmental risk analysis and outlines the use of the model, PROTEUS. Chapter 8 goes into the subject of the use of new models and Chapter 9 considers some aspects of uncertainty in a QRA calculation.

Data values given in this report are set by consensus following discussions between representatives from industry, the competent authorities and the central government. Data values are often based on previously made decisions using best judgement of the available information at that time. A number of chapters have been completed with an appendix, called ‘Commentary’, to provide a record of the reasoning leading to specific data. These ‘commentaries’ discuss motivation for certain decisions and the base used for specific data and their validity.

Finally, please note that the information in this document should be used as a guideline to a QRA calculation. The author of a QRA may deviate from the recommendations given here if site-specific information demands it. However, deviations should be made in consultation with and be approved by the competent authorities, with the motivation documented in the QRA report.

2. SELECTION OF THE INSTALLATIONS FOR THE QRA

2.1 Introduction

A Quantitative Risk Assessment (QRA) is a valuable tool for determining the risk of the use, handling, transport and storage of dangerous substances. QRAs are done if dangerous substances are thought to be present at a location (e.g. industrial sites and transportation routes) in amounts that can endanger the environment. A QRA is used in a Safety Report to demonstrate the risk caused by the establishment and to provide the competent authority with relevant information for assessing incremental risk and for enabling decisions on the acceptability of risk related to developments on site of or around the establishment. A Safety Report should be made if the amount of dangerous substances that can be present in an establishment exceeds a threshold value [EU96]. The procedure to determine whether a Safety Report has to be made is given in the Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances [EU96][a]. The procedure is outlined in Appendix 2.A.

The total number of installations in an establishment where a Safety Report has to be made can be very large. Since not all installations contribute significantly to the risk, it is not worthwhile to include all installations in the QRA. Therefore a selection method, described below, has been developed to indicate the installations that contribute most to the risk caused by the establishment. These installations have to be considered in the QRA.

The method to select the installations to be included in the QRA is a general one and should therefore be considered as a guidance only [NR]. Consequently, some installations can be unjustly omitted. Notable examples are loading and unloading facilities, inter-unit pipelines, (by-) products in the process, products formed through burning during a fire, combustion products and reaction products from run-away reactions.

The installations to be considered in the QRA are selected following consultation between the operator of an establishment and the competent authority. The operator of an establishment does the calculations needed to select installations. However, the selection of installations is the responsibility of the competent authority only. The competent authority can therefore decide to include installations in the QRA that are not selected using the method described here.

The selection method applies only to the establishments for which a Safety Report has to be made. If a QRA is made for transportation routes or other establishments, all installations have to be included in the QRA. However, the competent authority may accept the application of the selection method in these cases too.

In this chapter, the selection method is described. An example calculation is included in Appendix 2.B.

[a] The reference should be replaced with the corresponding Dutch legislation when appropriate.

2.2 Exclusion of particular substances

Following Article 9, Paragraph 6 of Council Directive 96/82/EC on the control of major-accident hazards involving dangerous substances [EU96], particular substances in a state incapable of creating a major-accident hazard can be excluded from the Safety Report and, consequently, from the QRA calculations. The decision is the responsibility of the competent authority. Criteria for the decision that substances are in a state incapable of creating a major hazard accident are given in the Commission decision on harmonized criteria for dispensations according to Article 9 of Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances [EU98]. A particular dangerous substance can be excluded if at least one of the following generic criteria is fulfilled.

1. Physical form of the substance

   Substances in solid form, such that, under both normal conditions and any abnormal conditions which can be reasonably foreseen, a release, of matter or of energy, which could create a major-accident hazard, is not possible.

2. Containment and Quantities

   Substances packaged or contained in such a fashion and in such quantities that the maximum release possible under any circumstances cannot create a major-accident hazard.

3. Location and Quantities

   Substances present in such quantities and at such distances from other dangerous substances (at the establishment or elsewhere) that they can neither create a major-accident hazard by themselves nor initiate a major accident involving other dangerous substances.

4. Classification

   Substances which are defined as dangerous substances by virtue of their generic classification in Annex I Part 2 of Council Directive 96/82/EC, but which cannot create a major-accident hazard, and for which therefore the generic classification is inappropriate for this purpose.

2.3 The selection method

If a Quantitative Risk Assessment has to be made as part of a Safety Report, it is not necessary to assess the risks of all installations of an establishment. However, it is important to consider all installations substantially contributing to the risk caused by an establishment. Therefore a selection method, based on the amount of substance present in an installation and on the process conditions, has been developed to determine which installations should be considered in a QRA. The selection method consisting of the following steps is illustrated in

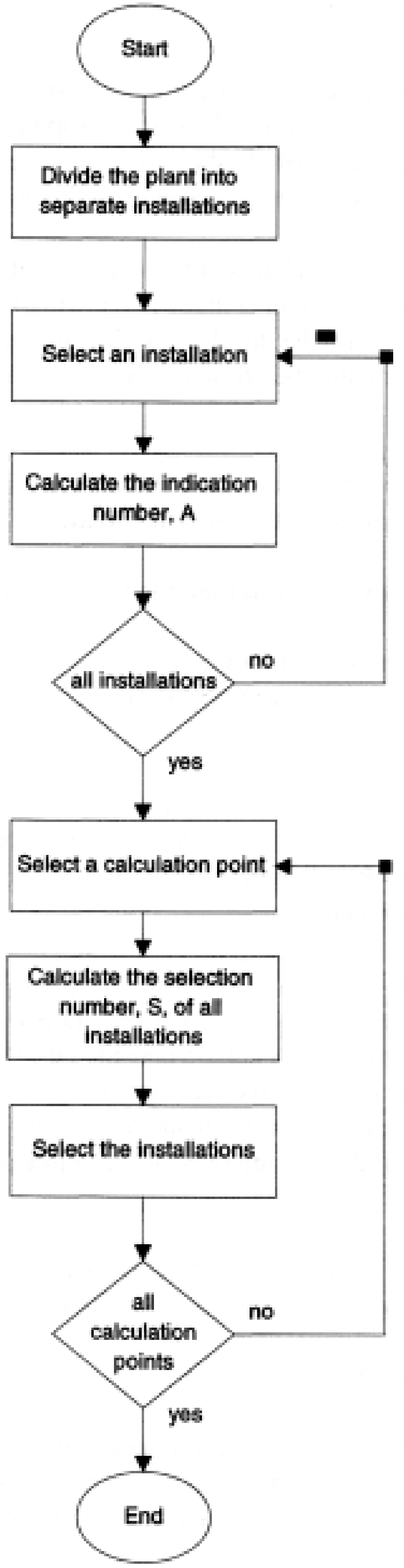

Figure 2.1 Outline of the selection method.

1. The establishment is divided into a number of independent installations, according to the procedure given in Section 2.3.1.

2. For all other installations, the intrinsic hazard, induced from the amount of substance present, the process conditions and the dangerous properties of the substance, is determined. The indication number, A, shows the measure of intrinsic hazard of the installation. This number is calculated according to the procedure given in Section 2.3.2.

3. The hazard of an installation is calculated for a number of points in the surroundings of the establishment. The hazard at a point is induced knowing the indication number and the distance between the point and the installation. The measure of the hazard at a given point is indicated by the selection number, S, which is calculated according to the procedure given in Section 2.3.3.

4. Installations are selected for analysis in the QRA on the basis of the relative magnitude of the selection number according to the procedure outlined in Section 2.3.4.

2.3.1 Definition of installations in an establishment

The first step in the selection method is to divide an establishment into a number of separate installations. This is a complex process, which may be open for discussion. This section offers some guidance.

An important criterion for the definition of a ‘separate installation’ is that loss of containment of one installation does not lead to release of significant amounts of substances from other installations. Consequently, two installations are considered separate if they can be isolated in a very short time following an accident.

Two different types of installations are distinguished, i.e. process installations and storage installations. A process installation can consist of several tanks, pipes and similar equipment. A storage installation, like a storage tank, is always considered to be separate. Often a storage installation is equipped with devices like recirculation systems and heat exchangers to keep the substance at storage conditions. However, the installation is still considered as a storage installation, whether or not such devices are present. The classification of transport units in an establishment is described in Section 2.3.5.

Since the division into separate installations is a complex process, consultation between the operator of the establishment and the competent authority is considered useful.

2.3.2 Calculation of the indication number, A

The intrinsic hazard of an installation depends on the amount of substance present, the physical and toxic properties of the substance and the specific process conditions. The indication number, A, is calculated as a measure of the intrinsic hazard of an installation.

The indication number, A, for an installation is a dimensionless number defined as:

$$A = \frac{Q \times O_1 \times O_2 \times O_3}{G} \qquad (2.1)$$

with:

Q the quantity of substance present in the installation (kg), as described in Section 2.3.2.1.
O_i the factors for process conditions (-), as described in Section 2.3.2.2.
G the limit value (kg), as described in Section 2.3.2.3.

2.3.2.1 Quantity of substance present, Q

The quantity of the substance present in an installation is the total amount of substance contained within the installation, where the desired and undesired generation of substances in the process should be considered, including a possible loss of control. The following rules apply:

- Mixtures and preparations can be distinguished into two different types, i.e. (1) a dangerous substance in a non-dangerous solvent and (2) a mixture of dangerous substances.
  (1) If a dangerous substance is dissolved in a non-dangerous substance, only the amount of dangerous substance has to be considered. Examples are ammonia in water or hydrogen chloride in water. Mixtures and preparations of toxic substances need to be taken into account in the selection process only if the mixture or preparation is classified as (very) toxic.
  (2) If a mixture of various dangerous substances has its own physical, chemical and toxic properties, it should be treated in the same way as pure substances.

- If dangerous substances are stored as small packaging units in one place and it is likely that loss of containment occurs for a large number of packaging units simultaneously, the total amount of the substance stored in that place has to be considered. Examples are the storage of explosives or fireworks and the release of toxic combustion products during a fire.

- For toxic substances in the solid state, only the amount of respirable powder has to be considered. However, also the possibility of a fire has to be considered. A fire will result in combustion products and an amount of unburned powder in the air.

- Storage tanks can be used to store different substances at different times. If large numbers of different substances are transshipped from an establishment, it is useful to classify the substances and to use sample substances for each category in the QRA. A classification method is described in [VVoW95]. It should be noted that if a specific substance constitutes an important part of the total amount transshipped, the substance itself will have to be considered.

2.3.2.2 Factors for process conditions, O_i

Three different factors are applied to account for process conditions:

O_1 a factor to account for process installation versus storage installation
O_2 a factor to account for the positioning of the installation

O_3 a factor to account for the amount of substance in the vapour phase after release, based on the process temperature, the atmospheric boiling point, the substance phase and the ambient temperature.

The factors for the process conditions apply to toxic and flammable substances only. For explosives, $O_1 = O_2 = O_3 = 1$.

2.3.2.2.1 Factor O_1

Factor O_1 (see Table 2.1) accounts for the type of installation, be it for processing or storage.

Table 2.1 Factor O_1 to account for the type of installation

Type	O_1
installation for processing	1
installation for storage	0.1

2.3.2.2.2 Factor O_2

Factor O_2 (see Table 2.2) accounts for the positioning of the installation and the presence of provisions to prevent the substances disseminating into the environment.

Table 2.2 Factor O_2 to account for the positioning of the installation

Positioning	O_2
outdoor installation	1.0
enclosed installation	0.1
installation situated in a bund and a process temperature, T_p, less than the atmospheric boiling point T_{bp} plus 5 °C, i.e. $T_p \leq T_{bp} + 5$ °C	0.1
installation situated in a bund and a process temperature, T_p, more than the atmospheric boiling point T_{bp} plus 5 °C, i.e. $T_p > T_{bp} + 5$ °C	1.0

Notes:

1. For storage, the process temperature should be seen as the storage temperature.

2. The enclosure of the installation should prevent substances being spread in the environment. This means that (a) the enclosure should remain unimpaired following the physical pressures due to the instantaneous release of the installation inventory and (b) the enclosure should reduce significantly the direct release into the atmosphere. A guideline: if the enclosure reduces the source term into the atmosphere by more than a factor 5, or if the enclosure redirects the release to a safe outlet, the installation will be considered enclosed, otherwise it is an outdoor installation.

3. A bund should prevent the substance spreading in the environment.

4. A second containment designed to contain the liquid and withstand all possible loads is interpreted as a ‘bund’, $O_2 = 0.1$. Factor 0.1 applies to double containment atmospheric tanks, full containment atmospheric tanks, in-ground atmospheric tanks and mounded atmospheric tanks.

2.3.2.2.3 Factor O_3

Factor O_3 (see Table 2.3) accounts for the process conditions and is a measure of the amount of substance in the gas phase after its release.

Table 2.3 Factor O_3 to account for the process conditions

Phase	O_3
substance in gas phase	10
substance in liquid phase	
- saturation pressure at process temperature of 3 bar or higher	10
- saturation pressure at process temperature of between 1 to 3 bar	$X + \Delta$
- saturation pressure at process temperature of less than 1 bar	$P_i + \Delta$
substance in solid phase	0.1

Notes:

1. For storage, the process temperature should be seen as the storage temperature..

2. Pressures are absolute.

3. Factor X increases linearly from 1 to 10 as the saturation pressure at process temperature, P_{sat}, increases from 1 to 3 bar. In the equation, where P_{sat} is given in bars:

$$X = 4.5 \times P_{sat} - 3.5 \qquad (2.2)$$

4. P_i is equal to the partial vapour pressure (in bars) of the substance at process temperature.

5. If the substance is in the liquid phase, an amount, Δ , is added to account for the extra evaporation due to the heat flux from the environment to the liquid pool formed. The value of Δ (see Table 2.4) depends only on the atmospheric boiling point, T_{bp}

Table 2.4 Added value Δ accounts for liquid pool evaporation

	Δ
$-25\ °C \le T_{bp}$	0
$-75\ °C \le T_{bp} < -25\ °C$	1
$-125\ °C \le T_{bp} < -75\ °C$	2
$T_{bp} < -125\ °C$	3

A 10% point should be used for mixtures of dangerous substances, i.e. the temperature at which 10% of the mixture is distilled off.

6. For dangerous substances in non-dangerous solvents, the partial vapour pressure of the dangerous substance at process temperature is to be used for the saturation pressure at process temperature. The factor X increases linearly from 1 to 10 if the partial vapour pressure of the dangerous substance at process temperature increases from 1 to 3 bar.

7. The factor O_3 is limited to a minimum value of 0.1 and a maximum value of 10.

2.3.2.3 Limit value, G

The limit value, G, is a measure of the dangerous properties of the substance based on both the physical properties and the toxic/explosive/flammable properties of the substance.

2.3.2.3.1 Limit value for toxic substances

The limit value for toxic substances (see Table 2.5) is determined by the lethal concentration, LC_{50}(rat, inh, 1h) and the phase at 25 °C.

Notes:

1. The phase of the substance (gas, liquid and solid) assumes a temperature of 25 °C. In addition, the following subdivision holds for liquids:
   - Liquid (L) atmospheric boiling point T_{bp} between 25 °C and 50 °C
   - Liquid (M) atmospheric boiling point T_{bp} between 50 °C and 100 °C
   - Liquid (H) atmospheric boiling point T_{bp} above 100 °C

2. LC_{50}(rat, inh, 1h) is the LC_{50} value for rats using an inhalation method for exposure of one hour. These values are listed for a number of toxic substances in the database [RIVM99].

3. The limit value should be derived from Table 2.5. Limit values to determine the Report on Occupational Safety compliance are listed for a number of substances in [SZW97] and [RIVM99]. These values can differ from those derived from Table 2.5 for some carcinogenic substances and if new toxicity data are used.

Table 2.5 Limit value, G, for toxic substances

LC_{50} (rat, inh, 1h) (mg m^{-3})	Phase at 25 °C	Limit value (kg)
LC ≤ 100	gas	3
	liquid (L)	10
	liquid (M)	30
	liquid (H)	100
	solid	300
100 < LC ≤ 500	gas	30
	liquid (L)	100
	liquid (M)	300
	liquid (H)	1000
	solid	3000
500 < LC ≤ 2000	gas	300
	liquid (L)	1000
	liquid (M)	3000
	liquid (H)	10,000
	solid	∞
2000 < LC ≤ 20,000	gas	3000
	liquid (L)	10,000
	liquid (M)	∞
	liquid (H)	∞
	solid	∞
LC > 20,000	all phases	∞

2.3.2.4 Limit value for flammable substances

The limit value for flammables is 10,000 kg.

Note:

1. Flammables are defined for the selection system as substances having a process temperature equal to or higher than the flashpoint. The flashpoint is determined using the apparatus of Abel-Pensky for flame points up to and including 65 ^{0}C and the apparatus of Pensky-Martens for flame points higher than 65 ^{0}C.

2.3.2.5 Limit value for explosive substances

The limit value for explosive substances is the amount of substance (in kg) which releases an amount of energy equivalent to 1000 kg TNT (explosion energy 4600 kJ/kg).

2.3.2.6 Calculation of the indication number

The indication number, A_i, of an installation for a substance *i* is calculated as:

$$A_i = \frac{Q_1 \times O_1 \times O_2 \times O_3}{G_i} \qquad (2.3)$$

with:

Q_i the quantity of substance *i* present in the installation (in kg)
O_1 the factor for installation type, whether process or storage (-)
O_2 the factor for the positioning of the installation, enclosed, bund or outdoors (-)
O_3 the factor for the process conditions (-)
G_i the limit value of substance *i* (in kg).

For explosives, $O_1 = O_2 = O_3 = 1$ and, consequently, $A = Q / G$.

Various substances and process conditions can be present within one installation. In this case, an indication number, $A_{i,p}$, is calculated for every substance, *i*, and for every process condition, *p*. The indication number, A, for an installation is calculated as the sum over all indication numbers, $\Sigma_{i,p} A_{i,p}$. This sum is calculated for three different groups of substances separately, namely, flammables (A^F), toxics (A^T) and explosives (A^E).

$A^T = \Sigma_{i,p} A_{i,p}$, sum over all toxic substances and process conditions
$A^F = \Sigma_{i,p} A_{i,p}$, sum over all flammable substances and process conditions
$A^E = \Sigma_{i,p} A_{i,p}$, sum over all explosive substances and process conditions

An installation can have up to three different indication numbers.

Note:

1. If a substance belongs to more than one group, an indication number is calculated for each group separately. For instance, if a substance is both toxic and flammable, two indication numbers, $A_{i,p}$, are calculated:
    - $A^T_{i,p}$ for the substance as a toxic using the total quantity, Q_i, and the limit value, G^T_i, corresponding with the toxic properties.
    - $A^F_{i,p}$ for the substance as a flammable using the total quantity, Q_i, and the corresponding limit value for flammables, G^F_i = 10,000 kg.

2.3.3 Calculation of the selection number, S

The selection number, S, is a measure of the hazard of an installation at a specific location and is calculated by multiplying the indication number, A, of an installation by a factor $(100/L)^2$ for toxic substances and a factor $(100/L)^3$ for flammable or explosive substances. Again, three different selection numbers can exist for one installation:

$$S^T = \left(\frac{100}{L}\right)^2 A^T \qquad \text{for toxics} \qquad (2.4)$$

$$S^F = \left(\frac{100}{L}\right)^3 A^F \qquad \text{for flammables} \qquad (2.5)$$

$$S^E = \left(\frac{100}{L}\right)^3 A^E \qquad \text{for explosives} \qquad (2.6)$$

L is the distance from the installation to the specific location in metres, with a minimum of 100 m.

The selection number has to be calculated for every installation at a minimum of eight locations on the boundary of the establishment. The distance between two adjacent locations must not be more than 50 metres. The selection number must be calculated for the total boundary of the establishment, even if the establishment borders on a similar establishment. If the establishment is bounded by surface water, the selection number must be calculated on the bank side situated opposite the establishment.

Besides the calculation on the boundary of the establishment, the selection number, S, must also be calculated for every installation at a location in a residential area, existing or planned, closest to the installation.

2.3.4 Selection of installations

An installation is selected for analysis in a QRA if:

- the selection number of an installation is larger than one at a location on the boundary of the establishment (or on the bank side situated opposite the establishment) and larger than 50% of the maximum selection number at that location.

or

- the selection number of an installation is larger than one at a location in the residential area, existing or planned, closest to the installation.

Note:

1. The effects of the release of toxic substances may extend further than the effects of the release of flammable substances. If only installations with flammable substances are selected and the selection number of an installation with a toxic substance is in the same order of magnitude as the maximum selection number, the installation with toxic substances should also be included.

2.3.5 Specific problems

2.3.5.1 Inter-unit pipelines

Large inter-unit pipelines in an establishment can contribute considerably to the risk caused by the establishment e.g.:

- inter-unit pipelines may be situated near the boundary of an establishment,
- inter-unit pipelines may release large amounts of substances due to their own hold-up and the feed from the upstream vessel, and
- inter-unit pipelines may have large failure frequencies.

For the selection method, the quantity present is calculated as:
- For pipelines containing liquids or pure gases, the quantity present is set equal to the amount in the pipeline, with a length equal to 600 seconds multiplied by the velocity of the liquid or gas in the pipeline.
- For pipelines containing liquefied pressurized gases, the quantity present is a function of the diameter of the pipeline and the substance. The quantity present is equal to the amount present in a pipeline, with a length that is emptied after 600 seconds. For a number of reference substances, the length of the pipeline emptied is given in Figure 1.2. For all other substances, the length can be estimated using the physical properties of the substance, particularly vapour pressure at 10 °C, to select one of the curves in Figure 1.2.

If the length of the pipeline calculated exceeds the actual length of the pipeline, the quantity present is equal to the amount between two quick-closing blocking valves isolating the pipeline at an incident. The time needed to close the two blocking valves is assumed to be so short that the amount released when the blocking valves are open is small compared to the amount between the two blocking valves. If not, the amount between the two blocking valves should be corrected with the mass released during the time the blocking valves are open. However, the quantity present should not exceed the amount in the length of the pipeline equal to 600 seconds multiplied by the velocity of the liquid or gas, or the length of the pipeline emptied after 600 sec (liquefied pressurized gases).

The factors for the process conditions O_1 - O_3 apply. An inter-unit pipeline should be considered as a process installation, $O_1 = 1$. The factors O_2 and O_3 are given in Table 2.2 and Table *2.3*. An underground inter-unit pipeline is to be considered enclosed ($O_2 = 0.1$).

To calculate the selection number, various points on the pipeline should be considered for the location of the total quantity present. The distance between two neighbouring points must be equal to circa 50 metres.

To select pipelines for a QRA calculation, a division is made in pipelines included in the establishment’s permit and pipelines not included. If an inter-unit pipeline is included in the permit, the pipeline should be dealt with like all other installations. However, if an inter-unit pipeline is not included in the permit, the installations without these inter-unit pipelines are first selected. This results in a list of installations in the establishment. Next, a new selection is made to include the inter-unit pipelines not included in the permit. This results in an additional list of inter-unit pipelines to be considered in the QRA.

If an inter-unit pipeline is selected on the basis of the selection number of one or more release locations, the total inter-unit pipeline will have to be included in the QRA.

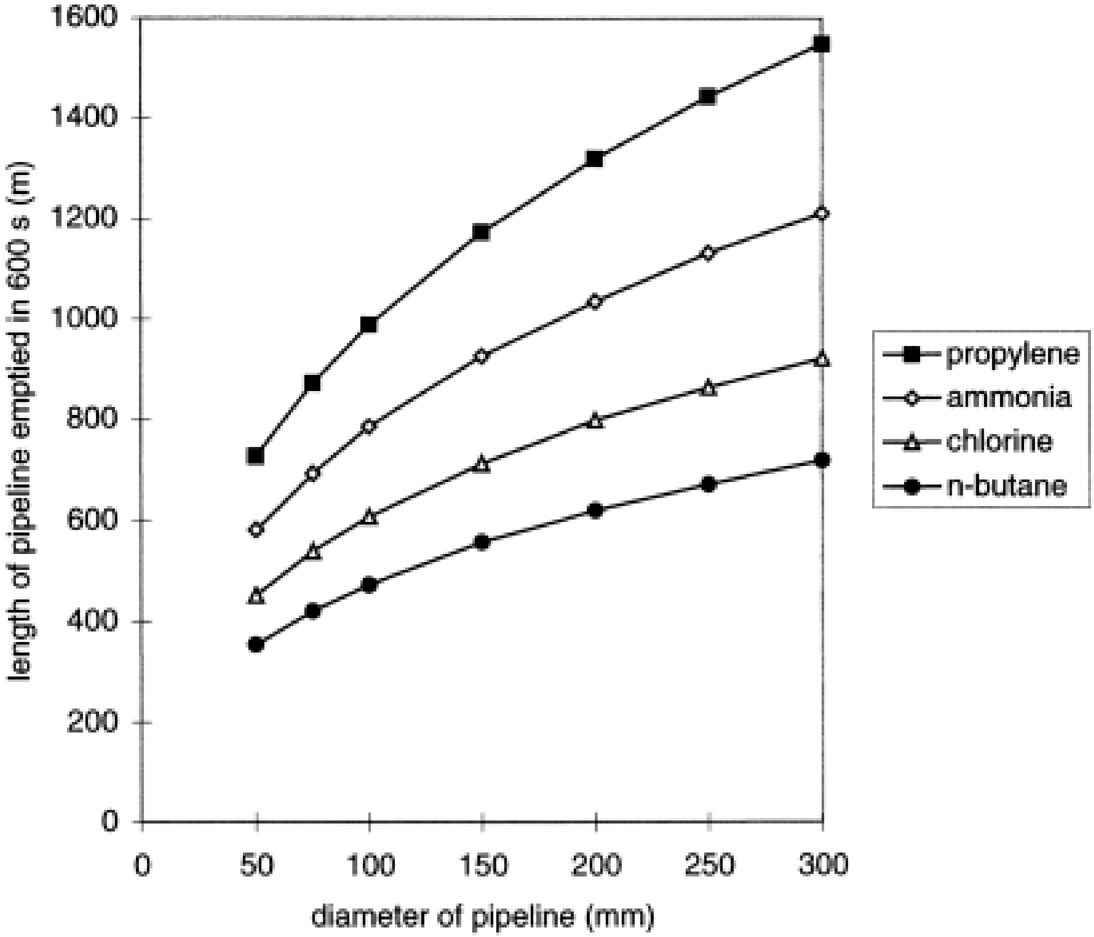

Figure 2.2 Length of pipeline emptied after 600 s for a number of reference substances for a two phase outflow at 10 °C.

2.3.5.2 Loading and unloading activities

During loading and unloading activities, storage tanks are situated within the transport unit at the establishment. Three installations have to be considered for the selection procedure, namely, the storage tank in the transport unit, the loading facility and the connecting installation at the establishment. The following rules apply:

- the storage tank in the transport unit is considered a ‘process installation’ if the time that the transport unit is connected to a process installation is less than one day. In all other cases, the storage tank in the transport unit is considered to be a ‘storage installation’.
- the loading facility is a process installation and should be included in the QRA if either the supplying or the receiving installation is selected.

- Storage tanks on ships should be included if the presence of the ship is connected to the establishment. Only the substances involved in loading and unloading activities have to be considered for the selection. If a storage tank on a ship is to be considered, installations without the storage tank on the ship are first selected. This results in a list of installations of the establishment. Next, a new selection is made of installations with the storage tank on the ships included. This results in an additional list of installations for consideration in the QRA.

- Transport units are only present part of the time. Although this is important in the QRA, it is not considered in the selection procedure.

Appendix 2.A Procedure to assess the obligation to make a Safety Report

2.A.1 Outline of the procedure

The procedure, outlined below, to determine whether a Safety Report should be obligatory was taken up in the Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances [EU96]. It should be noted that the outline given here is only a short description of the framework and should not be seen as the complete procedure. The rules and notes in Annex I of the Council Directive 96/82/EC of 9 December 1996, taken up in 2.A.2, are decisive and should be considered carefully.

The procedure:

1. Determine the substances present in the establishment. 'Presence' of substances is taken to mean the actual or anticipated presence of such substances in the establishment, or the presence of those substances believed to be possibly generated during a chemical process which has got out of control.

   Notes:
   - If a substance is licensed, it is assumed to be present.
   - The presence of a substance is meant to refer to a substance in the establishment for at least five consecutive days or at a frequency of more than 10 times per year.

2. Determine for each substance, x, the maximum quantity present or likely to be present at any one time, q_x.

   Note:
   - The licensed amount of substance is assumed to be present.

3. Look for the substance x in the table of Part 1 of Annex I
   - If substance x is named in the table of Part 1, determine the corresponding qualifying quantity, Q_x , in column 3 (Article 9).
   - If substance x is not named in the table of Part 1, determine in which category of the table the substance falls. Determine the corresponding qualifying quantity, Q_x , in column 3 (Article 9).

4. Determine for each substance x the value q_x / Q_x . If $q_x / Q_x > 1$ for one or more of the substances, a Safety Report should be made.

5. If $q_x / Q_x < 1$ for all substances x, the sum $q_1 / Q_1 + q_2 / Q_2 + q_3 / Q_3 + ...$ has to be calculated for two groups of substances separately, namely, for all substances classified in the categories 1, 2 and 9, and for all substances classified in the categories 3, 4, 5, 6, 7a, 7b, and 8. If one of the two sums is larger than 1, a Safety Report should be made.
   Named substances should be classified and added accordingly to the categories in the table of Part 2, using the qualifying quantity Q_x of the table in Part 1.

There are databases available which give the classification of a number of dangerous substances, e.g. the database of substances of RIVM [RIVM99].

2.A.2 Annex I of the Council Directive 96/82/EC of 9 December 1996

APPLICATION OF THE DIRECTIVE

INTRODUCTION

1. This Annex applies to the presence of dangerous substances at any establishment within the meaning of Article 3 of this Directive and determines the application of the relevant Articles thereof.
2. Mixtures and preparations shall be treated in the same way as pure substances provided they remain within concentration limits set according to their properties under the relevant Directives given in Part 2, Note 1, or their latest adaptation to technical progress, unless a percentage composition or other description is specifically given.
3. The qualifying quantities set out below relate to each establishment.
4. The quantities to be considered for the application of the relevant Articles are the maximum quantities which are present or are likely to be present at any one time. Dangerous substances present at an establishment only in quantities equal to or less than 2 % of the relevant qualifying quantity shall be ignored for the purposes of calculating the total quantity present if their location within an establishment is such that it cannot act as an initiator of a major accident elsewhere on the site.
5. The rules given in Part 2, Note 4, governing the addition of dangerous substances, or categories of dangerous substances, shall apply where appropriate.

PART 1

Named substances

Where a substance or group of substances listed in Part 1 also falls within a category of Part 2, the qualifying quantities set out in Part 1 must be used.

Column 1	Column 2	Column 3
Dangerous substances	Qualifying quantity (tonnes) for the application of	
	Articles 6 and 7	Article 9
Ammonium nitrate	350	2500
Ammonium nitrate	1250	5000
Arsenic pentoxide, arsenic (V) acid and/or salts	1	2
Arsenic trioxide, arsenious (III) acid and/or salts		0,1
Bromine	20	100
Chlorine	10	25
Nickel compounds in inhalable powder form (nickel monoxide, nickel dioxide, nickel sulphide, trinickel disulphide, dinickel trioxide)		1
Ethyleneimine	10	20
Fluorine	10	20
Formaldehyde (concentration ≥ 90 %)	5	50
Hydrogen	5	50
Hydrogen chloride (liquefied gas)	25	250
Lead alkyls	5	50

Column 1	Column 2	Column 3
Dangerous substances	Qualifying quantity (tonnes) for the application of	
	Articles 6 and 7	Article 9
Liquefied extremely flammable gases (including LPG) and natural gas	50	200
Acetylene	5	50
Ethylene oxide	5	50
Propylene oxide	5	50
Methanol	500	5000
4, 4-Methylenebis (2-chloraniline) and/or salts, in powder form		0.01
Methylisocyanate		0.15
Oxygen	200	2000
Toluene diisocyanate	10	100
Carbonyl dichloride (phosgene)	0.3	0.75
Arsenic trihydride (arsine)	0.2	1
Phosphorus trihydride (phosphine)	0.2	1
Sulphur dichloride	1	1
Sulphur trioxide	15	75
Polychlorodibenzofurans and polychlorodibenzodioxins (including TCDD), calculated in TCDD equivalent		0,001
The following CARCINOGENS: 4-Aminobiphenyl and/or its salts, Benzidine and/or salts, Bis (chloromethyl) ether, Chloromethyl methyl ether, Dimethylcarbamoyl chloride, Dimethylnitrosomine, Hexamethylphosphoric triamide, 2-Naphtylamine and/or salts, and 1,3 Propanesultone 4-nitrodiphenyl	0,001	0.001
Automotive petrol and other petroleum spirits	5000	50,000

NOTES

1. *Ammonium nitrate (350 / 2500)*

This applies to ammonium nitrate and ammonium nitrate compounds in which the nitrogen content as a result of the ammonium nitrate is more than 28 % by weight (compounds other than those referred to in Note 2) and to aqueous ammonium nitrate solutions in which the concentration of ammonium nitrate is more than 90 % by weight.

2. *Ammonium nitrate (1250/5000)*

This applies to simple ammonium-nitrate based fertilizers which comply with Directive 80/876/EEC and to composite fertilizers in which the nitrogen content as a result of the ammonium nitrate is more than 28% in weight (a composite fertilizer contains ammonium nitrate with phosphate and/or potash).

3. *Polychlorodibenzofurans and polychlorodibenzodioxins*

The quantities of polychlorodibenzofurans and polychlorodibenzodioxins are calculated using the following factors:

International Toxic Equivalent Factors (ITEF) for the congeners of concern (NATO/CCMS)			
2,3,7,8-TCDD	1	2,3,7,8-TCDF	0.1
1,2,3,7,8-PeDD	0.5	2,3,4,7,8-PeCDF	0.5
		1,2,3,7,8-PeCDF	0.05
1,2,3,4,7,8-HxCDD	0.1		
1,2,3,6,7,8-HxCDD	0.1	1,2,3,4,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDD	0.1	1,2,3,7,8,9-HxCDF	0.1
		1,2,3,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDD	0.01	2,3,4,6,7,8-HxCDF	0.1
OCDD	0.001	1,2,3,4,6,7,8-HpCDF	0.1
		1,2,3,4,7,8,9-HpCDF	0.01
		OCDF	0.01

(T = tetra, P = penta, Hx = hexa, Hp = hepta, O = octa)

PART 2

Categories of substances and preparations not specifically named in Part 1

Column 1		Column 2	Column 3
Categories of dangerous substances		Qualifying quantity (tonnes) of dangerous substances as delivered in Article 3 (4), for the application of	
		Articles 6 and 7	Article 9
1.	VERY TOXIC	5	20
2.	TOXIC	50	200
3.	OXIDIZING	50	200
4.	EXPLOSIVE (where the substance or preparation falls within the definition given in Note 2 (a))	50	200
5.	EXPLOSIVE (where the substance or preparation falls within the definition given in Note 2 (b))	10	50
6.	FLAMMABLE (where the substance or preparation falls within the definition given in Note 3 (a))	5000	50,000
7 a.	HIGHLY FLAMMABLE (where the substance or preparation falls within the definition given in Note 3 (b) (1))	50	200
7 b.	HIGHLY FLAMMABLE liquids (where the substance or preparation falls within the definition given in Note 3 (b) (2))	5000	50,000
8.	EXTREMELY FLAMMABLE (where the substance or preparation falls within the definition given in Note 3 (c))	10	50
9.	DANGEROUS FOR THE ENVIRONMENT in combination with risk phrases:		
	(i) R50: ‘Very toxic to aquatic organisms’	200	500
	(ii) R51:’Toxic to aquatic organisms’; and R53: ‘May cause long term adverse effects in the aquatic environment’	500	2000
10.	ANY CLASSIFICATION not covered by those given above in combination with risk phrases:	100	500
	(i) R14: ‘Reacts violently with water’ (including R14/15)	50	200
	(ii) R29: ‘in contact with water, liberates toxic gas’		

NOTES

1. Substances and preparations are classified according to the following Directives (as amended) and their current adaptation to technical progress:

— Council Directive 67/548/EEC of 27 June 1967 on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances (b),

— Council Directive 88/379/EEC of 7 June 1988 on the approximation of the laws, regulations and administrative provisions of the Member States relating to the classification, packaging and labelling of dangerous preparations (c),

— Council Directive 78/631/EEC of 26 June 1978 on the approximation of the laws of the Member States relating to the classification, packaging and labelling of dangerous preparations (pesticides) (d).

In the case of substances and preparations which are not classified as dangerous according to any of the above Directives but which nevertheless are present, or are likely to be present, in an establishment and which possess or are likely to possess, under the conditions found at the establishment, equivalent properties in terms of major-accident potential, the procedures for provisional classification shall be followed according to the relevant Article of the appropriate Directive.

In the case of substances and preparations with properties giving rise to more than one classification , for the purposes of this Directive the lowest thresholds shall apply.

For the purposes of this Directive, a list providing information on substances and preparations shall be established, kept up to date and approved by the procedure set up under Article 22.

2. An 'explosive' means:

(a) (i) a substance or preparation which creates the risk of an explosion by shock, friction, fire or other sources of ignition (risk phrase R 2),

(ii) a pyrotechnic substance is a substance (or mixture of substances) designated to produce heat, light, sound, gas or smoke or a combination of such effects through non-detonating self-sustained exothermic chemical reactions, or

(iii)an explosive or pyrotechnic substance or preparation contained in objects;

(b) a substance or preparation which creates extreme risks of explosion by shock, friction, fire or other sources of ignition (risk phrase R 3).

3. 'Flammable', 'highly flammable', and 'extremely flammable' in categories 6, 7 and 8 mean:

(a) flammable liquids:

substances and preparations having a flash point equal to or greater than 21 °C and less than or equal to 55°C (risk phrase R 10), supporting combustion;

(b) highly flammable liquids:

1. — substances and preparations which may become hot and finally catch fire in contact with air at ambient temperature without any input of energy (risk phrase R 17),

— substances which have a flash point lower than 55 °C and which remain liquid under pressure, where particular processing conditions, such as high pressure or high temperature, may create major-accident hazards;

2. substances and preparations having a flash point lower than 21 °C and which are not extremely flammable (risk phrase R 11, second indent);

(b) OJ No. 196, 16. 8. 1967, p. 1. Directive as fast *<OK?>* amended by Directive 93/105/EC (OJ No. L 294, 30. 11. 1993, p. 21).

(c) OJ No. L 187, 16. 7. 1988, p. 14.

(d) OJ No. L 206, 29. 7. 1978, p. 13. Directive as fast amended by Directive 92/32/EEC (OJ No. L 154, 5. 6. 1992, p. 1).

(c) extremely flammable gases and liquids:

1. liquid substances and preparations which have a flash point lower than 0 °C and the boiling point (or, in the case of a boiling range, the initial boiling point) of which at normal pressure is less than or equal to 35 °C (risk phrase R 12, first indent), and
2. gaseous substances and preparations which are flammable in contact with air at ambient temperature and pressure (risk phrase R 12, second indent), whether or not kept in the gaseous or liquid state under pressure, excluding liquefied extremely flammable gases (including LPG) and natural gas referred to in Part 1, and
3. liquid substances and preparations maintained at a temperature above their boiling point.

4. The addition of dangerous substances to determine the quantity present at an establishment shall be carried out according to the following rule:

if the sum

$q_1/Q + q_2/Q + q_3/Q + q_4/Q + q_5/Q + ... > 1$,

where q_x = the quantity of dangerous substances x (or category of dangerous substances) falling within Parts 1 or 2 of this Annex,

Q = the relevant threshold quantity from Parts 1 or 2,

then the establishment is covered by the relevant requirements of this Directive.

This rule will apply for the following circumstances:

(a) for substances and preparations appearing in Part 1 at quantities less than their individual qualifying quantity present with substances having the same classification from Part 2, and the addition of substances and preparations with the same classification from Part 2;

(b) for the addition of categories 1, 2 and 9 present at an establishment together;

(c) for the addition of categories 3, 4, 5, 6, 7a, 7b and 8, present at an establishment together.

Appendix 2.B An example calculation

2.B.1 Description of the establishment and the installations

An establishment contains five separate installations. The area of the establishment is rectangular between the lower left point (–400 m, –200 m) and the upper right point (+300 m, +300 m). A residential area is situated to the north of the establishment, at 400 m from its centre.

The installations, I_i, are listed in Table 2.B.1.

Table 2.B.1 Installations, I_i, present at the establishment

No	Location	Process
I_1	(200, 200)	Production installation inside a building, containing pure chlorine in an amount of 2100 kg at a process temperature of 35 °C (vapour pressure at a process temperature of 10 bar)
I_2	(0, 0)	Production installation outdoors. The installation contains various flammable substances at different process conditions: ethylene amount 200,000 kg liquid at –30 °C (vapour pressure 20 bar) ethane amount 100,000 kg gas at 80 °C butane amount 10,000 kg gas at 30 °C propylene amount 10,000 kg liquid at –35 °C (vapour pressure 1.75 bar) propane amount 50,000 kg liquid at 80 °C (vapour pressure 31 bar)
I_3	(–300,–150)	Installation for storage of a 30% solution of hydrochloric acid in water. The storage tank is situated outdoors and contains 1,500,000 kg solution at a temperature of 25 °C (partial vapour pressure P_i = 0.02 bar).
I_4	(200, 100)	The storage tank is connected to a process installation inside a building where an amount of 300,000 kg of the 30% solution of hydrochloric acid in water is processed at a temperature of 100 °C (liquid, partial vapour pressure of P_i = 1.1 bar).
I_5	(–300,–125)	A process installation outdoors contains pure ammonia (gas, 12,000 kg), a 60% solution of ammonia in water (9000 kg solution at 43 °C, with a partial vapour pressure P_i = 9.4 bar). In the installation petrol is used (1000 kg) at a temperature of 150 °C.

The layout of the plant and the residential area is shown in Figure 2.B.1.

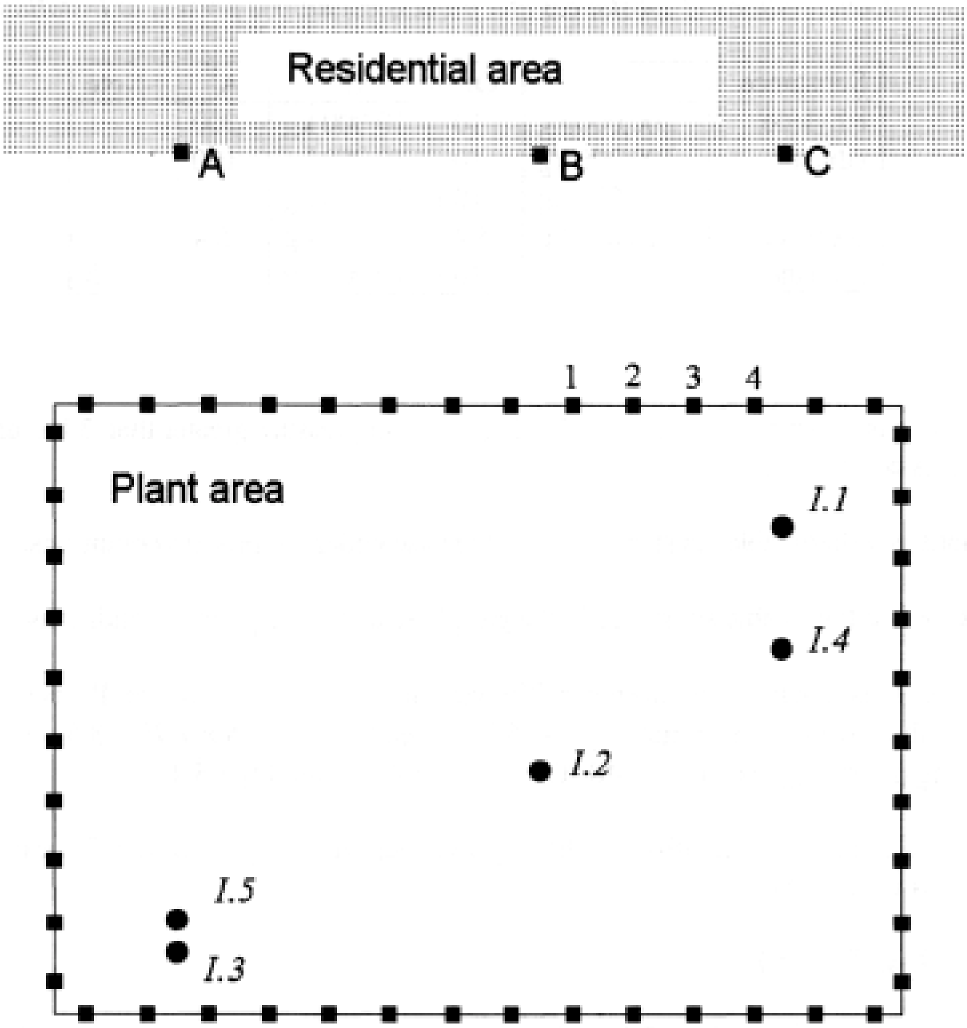

Figure 2.B.1 Layout of the plant and residential area, showing points closest to the installation (A-C). Indicated are the locations (solid circle) of the installations (I.1-I.5) and the locations (solid square) where the selection numbers are calculated. The locations 1, 2, 3, .. and A-C correspond with the points in Table 2.B.5.

2.B.2 Calculation of the indication number

2.B.2.1 Installation I_1

Installation I_1 is a process installation (O_1 = 1) situated in a building (O_2 = 0.1). One substance, chlorine, is present in a quantity Q of 2100 kg. As the vapour pressure of chlorine is more than 3 bar, O_3 = 10. Chlorine is a toxic substance; in the gas phase at 25 °C; LC_{50}(rat, ihl, 1hr) = 293 ppm [SZW97]. The limit value is equal to G = 300 kg. Therefore, A^T_1 = 7.

2.B.2.2 Installation I_2

Installation I_2 is a process installation (O_1 = 1) situated outdoors (O_2 = 1). Five different combinations of substances and process conditions are present, as shown in Table 2.B.2.

Table 2.B.2 Combinations of substances and process conditions present at Installation I_2

Substance	Q	O_3	G	A^F	Note
ethylene	200,000 kg	10	10,000 kg	200	1
ethane	100,000 kg	10	10,000 kg	100	2
butane	10,000 kg	10	10,000 kg	10	3
propylene	10,000 kg	5.4	10,000 kg	5.4	4
propane	50,000 kg	10	10,000 kg	50	5

Notes:

1. Ethylene is a flammable substance having a vapour pressure greater than 3 bar under the process conditions.

2. Ethane is a flammable substance in the gas phase under the process conditions.

3. Butane is a flammable substance in the gas phase under the process conditions.

4. Propylene is a flammable substance. The vapour pressure of propylene, P_i , is equal to 1.75 bar at the process temperature, $T_p = -35$ °C. Therefore $X = 4.5 \times 1.75 - 3.5 = 4.4$. The boiling point, T_{bp}, is equal to -48 °C. Therefore $\Delta = 1$ and $O_3 = 5.4$.

5. Propane is a flammable substance having a vapour pressure greater than 3 bar under the process conditions.

2.B.2.3 Installation I_3

Installation I_3 is for storage ($O_1 = 0.1$) and situated outdoors ($O_2 = 1$). The amount of hydrogen chloride present is 30% of 1,500,000 kg solution; Q = 450,000 kg. The substance, 30% solution of hydrochloric acid in water, is a liquid. The partial vapour pressure of the dangerous substance, hydrogen chloride, is $P_i = 0.02$ bar; therefore X = 0.02. The boiling point of the substance, 30% solution of hydrochloric acid in water, is 57 °C, so $\Delta = 0$. As the resulting O_3 is less than the minimum value, 0.1, $O_3 = 0.1$. Hydrogen chloride is a toxic substance and in the gas phase at 25 °C; LC_{50}(rat, ihl, 1hr) = 3124 ppm [SZW97]. The limit value is equal to G = 3000 kg. Therefore $A^T{}_3 = 1.5$.

2.B.2.4 Installation I_4

Installation I_4 is a process installation ($O_1 = 1$) and situated inside a building ($O_2 = 0.1$). The amount of hydrogen chloride present is 30% of 300,000 kg solution; Q = 90,000 kg. The partial vapor pressure of hydrochloric acid is $P_i = 1.1$ bar at $T_p = 100$ °C. The factor $X = 4.5 \times 1.1 - 3.5 = 1.5$. The boiling point of the substance, 30% solution of hydrochloric acid in water, is 57 °C, so $\Delta = 0$ and $O_3 = 1.5$. The limit value is equal to G = 3000 kg. Therefore $A^T{}_4 = 4.5$.

2.B.2.5 Installation I_5

Installation I_5 is a process installation ($O_1 = 1$) and situated outdoors ($O_2 = 1$). Three combinations of substances and process conditions are present. Furthermore, ammonia is both toxic and flammable; both these hazards should be considered. The combinations of substances and process conditions are shown in Table 2.B.3.

Table 2.B.3 Combinations of substances and process conditions present at Installation I_5

Substance	Q	O_3	G	A^F	A^T	Note
ammonia, pure	12,000 kg	10	3,000 kg		40	1
ammonia, pure	12,000 kg	10	10,000 kg	12		1
ammonia, solution	5400 kg	10	3,000 kg		18	2
ammonia, pure	5400 kg	10	10,000 kg	5.4		2
petrol	1000 kg	10	10,000 kg	1		3

Notes:

1. Ammonia is a gas under the process conditions. The Limit value for the toxic substance ammonia is equal to 3000 kg since ammonia is a gas at 25 °C and LC_{50}(rat, inh., 1hr) = 11,590 mg m^{-3} [SZW97]. The limit value for the flammable substance ammonia is equal to 10,000 kg.

2. The quantity of ammonia present in solution is equal to 60% of 9000 kg solution, Q = 5400 kg. As the partial vapour pressure exceeds 3 bar, then O_3 = 10. The limit value for the toxic substance ammonia is equal to 3000 kg since ammonia is a gas at 25 °C and LC_{50}(rat, inh., 1hr) = 11,590 mg m^{-3} [SZW97]. The limit value for the flammable substance ammonia is equal to 10,000 kg.

3. Petrol is a flammable substance. The process temperature is higher than the 10% point. The vapour pressure at 150 °C has to be determined. For the example we assume it to be greater than 3 bar. Therefore O_3 = 10.

2.B.2.6 Summary

The result of calculating the indication number is summarised in Table 2.B.4.

The indication numbers are:

installation I_1 $A^T = 7$
installation I_2 $A^F = 365$
installation I_3 $A^T = 1.5$
installation I_4 $A^T = 4.5$
installation I_5 $A^T = 58$, $A^F = 18.4$

Table 2.B.4 Indication numbers of the installations

Inst.	Substance	Type	O_1	O_2	O_3	Q	G	A_i
I_1	chlorine	T	1	0.1	10	2100 kg	300 kg	7
I_2	ethylene	F	1	1	10	200,000 kg	10,000 kg	200
	ethane	F	1	1	10	100,000 kg	10,000 kg	100
	butane	F	1	1	10	10,000 kg	10,000 kg	10
	propylene	F	1	1	5.4	10,000 kg	10,000 kg	5.4
	propane	F	1	1	10	50,000 kg	10,000 kg	50
I_3	30%-HCl	T	0.1	1	0.1	450,000 kg	3000 kg	1.5
I_4	30%-HCl	T	1	0.1	1.5	90,000 kg	3000 kg	4.5
I_5	ammonia (g)	T	1	1	10	12,000 kg	3000 kg	40
	ammonia (s)	T	1	1	10	5400 kg	3000 kg	18
	ammonia (g)	F	1	1	10	12,000 kg	10,000 kg	12
	ammonia (s)	F	1	1	10	5400 kg	10,000 kg	5.4
	petrol	F	1	1	10	1000 kg	10,000 kg	1

2.B.3 Calculation of the selection number

The selection number has to be calculated for points on the site boundary and residential area. There are 48 points selected at 50-m intervals along the boundary (see Figure). Furthermore, for each installation the point in the plant area closest to the installation is selected. The selection number is calculated from the distance of each point to the installation (minimal 100 metres). The results are shown in Table 2.B.5. Installations 1, 2 and 5 have been selected for a QRA.

Table 2.B.5 Selection numbers at the positions selected

No.	x	y	S_1	S_2	S_3	S_4	S_5^T	S_5^F	Selected
1	25	300	1.7	13.4	0.0	0.6	2.0	0.1	2
2	75	300	2.7	12.3	0.0	0.8	1.8	0.1	2
3	125	300	4.5	10.6	0.0	1.0	1.6	0.1	2
4	175	300	6.6	8.7	0.0	1.1	1.4	0.1	1, 2
5	225	300	6.6	6.9	0.0	1.1	1.3	0.1	1, 2
6	275	300	4.5	5.4	0.0	1.0	1.1	0.0	1, 2
7	300	275	4.5	5.4	0.0	1.1	1.1	0.0	1, 2
8	300	225	6.6	6.9	0.0	1.8	1.2	0.1	1, 2
9	300	175	6.6	8.7	0.0	2.9	1.3	0.1	1, 2
10	300	125	4.5	10.6	0.0	4.2	1.4	0.1	2
11	300	75	2.7	12.3	0.0	4.2	1.5	0.1	2
12	300	25	1.7	13.4	0.0	2.9	1.5	0.1	2
13	300	−25	1.2	13.4	0.0	1.8	1.6	0.1	2
14	300	−75	0.8	12.3	0.0	1.1	1.6	0.1	2
15	300	−125	0.6	10.6	0.0	0.7	1.6	0.1	2
16	300	−175	0.5	8.7	0.0	0.5	1.6	0.1	2
17	275	−200	0.4	9.3	0.0	0.5	1.7	0.1	2
18	225	−200	0.4	13.4	0.1	0.5	2.1	0.1	2
19	175	−200	0.4	19.4	0.1	0.5	2.5	0.2	2
20	125	−200	0.4	27.8	0.1	0.5	3.1	0.2	2
21	75	−200	0.4	37.5	0.1	0.4	4.0	0.3	2
22	25	−200	0.4	44.6	0.1	0.4	5.2	0.5	2
23	−25	−200	0.3	44.6	0.2	0.3	7.1	0.8	2
24	−75	−200	0.3	37.5	0.3	0.3	10.3	1.3	2
25	−125	−200	0.3	27.8	0.5	0.2	16.0	2.6	2, 5
26	−175	−200	0.2	19.4	0.8	0.2	27.3	5.8	2, 5
27	−225	−200	0.2	13.4	1.5	0.2	51.6	15.1	5
28	−275	−200	0.2	9.3	1.5	0.1	58.0	18.0	5
29	−325	−200	0.2	6.6	1.5	0.1	58.0	18.0	5
30	−375	−200	0.1	4.8	1.5	0.1	51.6	15.1	5
31	−400	−175	0.1	4.4	1.4	0.1	46.4	12.9	5
32	−400	−125	0.2	5.0	1.4	0.1	58.0	18.0	5
33	−400	−75	0.2	5.4	1.0	0.1	46.4	12.9	5
34	−400	−25	0.2	5.7	0.6	0.1	29.0	6.4	5
35	−400	25	0.2	5.7	0.4	0.1	17.8	3.1	5
36	−400	75	0.2	5.4	0.2	0.1	11.6	1.6	5
37	−400	125	0.2	5.0	0.2	0.1	8.0	0.9	2, 5
38	−400	175	0.2	4.4	0.1	0.1	5.8	0.6	2, 5
39	−400	225	0.2	3.8	0.1	0.1	4.4	0.4	2, 5
40	−400	275	0.2	3.2	0.1	0.1	3.4	0.3	2, 5
41	−375	300	0.2	3.3	0.1	0.1	3.1	0.2	2, 5
42	−325	300	0.2	4.2	0.1	0.1	3.2	0.2	2, 5
43	−275	300	0.3	5.4	0.1	0.2	3.2	0.2	2, 5
44	−225	300	0.4	6.9	0.1	0.2	3.1	0.2	2
45	−175	300	0.5	8.7	0.1	0.2	3.0	0.2	2
46	−125	300	0.6	10.6	0.1	0.3	2.7	0.2	2
47	−75	300	0.8	12.3	0.1	0.4	2.5	0.2	2
48	−25	300	1.2	13.4	0.1	0.5	2.3	0.1	2
C	200	400	1.8						1
B	0	400		5.7					2
A	−300	400			0.0				
C	200	400				0.5			
A	−300	400					2.1	0.12	5

Appendix 2.C Commentary

The procedure to select installations for the QRA is largely based on the references [IPO], [KO 9], [KO 12], [KO 19-2] and [NR].

In addition, the following changes are made:

- Section 2.2 describes the criteria to exclude particular substances from the QRA calculations. Article 9, Paragraph 6 of Council Directive 96/82/EC indicates that particular substances in a state incapable of creating a major-accident hazard can be excluded from the Safety Report [EU96]. The criteria to be used are given in the Commission decision on harmonized criteria for dispensations according to Article 9 of Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances [EU98]. Consequently, it has been decided to exclude these substances from the QRA calculations using the same criteria.

- Section 2.3.2.1 records the rule on whether mixtures and preparations of toxic substances need to be considered. This rule has been changed. Previously, dangerous substances in concentrations less than 5% did not need to be considered. This rule is now replaced by the limits of the corresponding EU directives [EU88].

- To facilitate QRA calculations in case many different substances are stored at different times, the use of sample substances has been added in Section 2.3.2.1.

- The factor O_3 accounts for the process conditions and is a measure of the amount of substance in the gas phase after the release (see Section 2.3.2.2.3). In the calculation of O_3, an amount Δ is used to account for the extra evaporation due to the heat flux from the environment to the liquid pool formed. The use of the amount Δ deviates from the calculations used previously [P 172, IPO]. In [P 172, IPO], the amount Δ is only added if the process temperature is lower than the ambient temperature. This condition is omitted here for two reasons:
  - the addition of an amount Δ is meant to account for the extra evaporation caused by the heat flux of the environment to the liquid pool. Therefore it is more reasonable to have the value of Δ not dependent on the process temperature, but only on the difference between the atmospheric boiling point and the (fixed) ambient temperature.
  - In practice, this condition is likely not to be tested. The saturation pressure at process temperature for most substances will be higher than 3 bar if the process temperature is equal to or higher than 25 °C and the atmospheric boiling point is lower than –25 °C. A saturation pressure at a process temperature higher than 3 bar already results in the maximum value of X = 10.

- For substances in the liquid phase, a factor X is used to calculate the factor O_3 (see Section 2.3.2.2.3). The use of an interpolation for the factor X between 1 and 10 has not previously been clearly described for dangerous substances in non-dangerous solvents. The interpolation is introduced here to be more in line with pure substances.

- The calculation of the limit value, G, has been copied from [SZW97] (see Section 2.3.2.3). One modification is made: [SZW97] assigns a limit value of 1 kg to substances which are extremely toxic. Therefore a number of carcinogenic substances have a limit value of 1 kg, although acute effects are not known. Since the QRA is directed to short-term lethal effects, the category of extremely toxic substances is no longer included.

- The selection method for large inter-unit pipelines represents a new procedure not previously described. The two-phase outflow is calculated using PHAST V5.2 [DNV98]. The outflow is calculated for a pipeline connected to a large spherical vessel at a height of one metre. The mass of the pressurized liquefied gas in the vessel is equal to 500 ton, the filling grade is 0.9 and temperature T = 282 K. The length of the pipeline emptied in 600 seconds is determined iteratively. First, a pipeline length is postulated. Next, the mass released in 600 seconds following a rupture of the pipeline is calculated. Finally, the volume corresponding to the mass released and the pipeline length corresponding with this volume is calculated. Using the new pipeline length, the procedure is repeated until convergence occurs.

- Appendix 2.A describes to procedure to assess the obligation to make a Safety Report. The procedure is taken from [EU96]. The note describing the presence of a substance in step 1 is not stated in [EU96] but taken from [KO 12].

3. LOSS OF CONTAINMENT EVENTS

3.1 Introduction

This chapter describes the Loss of Containment events (LOCs) that need to be included in the QRA for establishments. The complete set of LOCs consists of generic LOCs, external-impact LOCs, loading and unloading LOCs and specific LOCs.

Generic LOCs
The generic LOCs cover all failure causes not considered explicitly, like corrosion, construction errors, welding failures and blocking of tank vents.

External-impact LOCs
LOCs for external impact are considered explicitly for transport units. The external-impact LOCs applying to stationary installations and pipelines are assumed to be either already included in the generic LOCs or should be included by adding an extra failure frequency.

Loading and unloading LOCs
Loading and unloading LOCs cover the transhipment of material from transport units to stationary installations and vice versa.

Specific LOCs
Specific LOCs cover the LOCs specific to the process conditions, process design, materials and plant layout. Examples are runaway reactions and domino effects.

Only LOCs that contribute to the individual and/or societal risk should be included in the QRA. This means that LOCs of an installation should be included only if two conditions are fulfilled: i.e. (1) frequency of occurrence is equal to or greater than 10^{-8} per year and (2) lethal damage (1% probability) occurs outside the establishment’s boundary or the transport route.

The LOCs for establishments are described in Sections 3.2.1 - 3.2.9.

3.2 Loss of Containment events at establishments

Loss of Containment events (LOCs) are defined for various systems in an establishment. The systems and their LOCs are described in more detail in the sections as indicated in Table 3.1.

Table 3.1 LOCs for systems in an establishment

System	Section
Stationary tanks and vessels, pressurised	3.2.1
Stationary tanks and vessels, atmospheric	3.2.2
Gas cylinders	3.2.1
Pipes	3.2.3
Pumps	3.2.4
Heat exchangers	3.2.5
Pressure relief devices	3.2.6
Warehouses	3.2.7
Storage of explosives	3.2.8
Road tankers	3.2.9
Tank wagons	3.2.9
Ships	3.2.9

3.2.1 Stationary pressurised tanks and vessels

Of the various types of pressurised stationary tanks and vessels, pressure, process and reactor vessels can be distinguished. These are described below.

Pressure vessel
A pressure vessel is a storage vessel in which the pressure is (substantially) more than 1 bar absolute.

Process vessel
In a process vessel a change in the physical properties of the substance occurs, e.g. temperature or phase. Examples of process vessels are distillation columns, condensers and filters. Vessels where only the level of liquid changes can be considered as pressure vessels.

Reactor vessel
In reactor vessels a chemical change of the substances occurs. Examples of reactor vessels are batch and continuous reactors. A vessel where a strong exothermic mixing of substances occurs should also be considered as a reactor vessel.

The LOCs for pressure, process and reactor vessels are given in Table 3.2, the failure frequencies of these LOCs for stationary vessels in
Table *3.3*.

Table 3.2 LOCs for stationary vessels

	LOC for stationary vessels
G.1	Instantaneous release of the complete inventory
G.2	Continuous release of the complete inventory in 10 min at a constant rate of release
G.3	Continuous release from a hole with an effective diameter of 10 mm

Table 3.3 Frequencies of LOCs for stationary vessels

Installation (part)	G.1 Instantaneous	G.2 Continuous, 10 min	G.3 Continuous, ∅10 mm
pressure vessel	5×10^{-7} y^{-1}	5×10^{-7} y^{-1}	1×10^{-5} y^{-1}
process vessel	5×10^{-6} y^{-1}	5×10^{-6} y^{-1}	1×10^{-4} y^{-1}
reactor vessel	5×10^{-6} y^{-1}	5×10^{-6} y^{-1}	1×10^{-4} y^{-1}

Notes:

1. A vessel or tank consists of the vessel (tank) wall and the welded stumps, mounting plates and instrumentation pipes. The LOCs cover the failure of the tanks and vessels and the associated instrumentation pipework. The failure of pipes connected to the vessels and tanks should be considered separately (see Section 3.2.3).

2. The failure frequencies given here are default failure frequencies based on the situation that corrosion, fatigue due to vibrations, operating errors and external impacts are excluded. A deviation of the default failure frequencies is possible in specific cases.
   - A lower failure frequency can be used if a tank or vessel has special provisions additional to the standard provisions, e.g. according to the design code, which have an indisputable failure-reducing effect. However, the frequency at which the complete inventory is released (i.e. the sum of the frequencies of the LOCs, G.1 and G.2) should never be less than 1×10^{-7} per year.
   - A higher frequency should be used if standard provisions are missing or under uncommon circumstances. If external impact or operating errors cannot be excluded, an extra failure frequency of 5×10^{-6} per year should be added to LOC G.1, ‘Instantaneous’ and an extra failure frequency of 5×10^{-6} per year should be added to LOC G.2, ‘Continuous, 10 min’.

3. Vessels and tanks can be (partly) in-ground, or situated inside or outside a building. The LOCs and their frequencies are not dependent on the situation. The modelling of a release inside a building is described in Chapter 4.

4. Storage tanks can be used for the storage of different substances at different times. If large numbers of different substances are transhipped from an establishment, it is useful to classify the substances and use sample substances for each category in the QRA. A classification method is described in [VVoW95]. It should be noted that if a specific substance makes up an important part of the total amount transhipped, the substance itself will have to be used in the calculation.

5. Storage tanks may have a pressure just above 1 bar absolute. These tanks have to be considered as atmospheric storage tanks. Examples are cryogenic tanks and atmospheric storage tanks with nitrogen blanketing.

6. The potential consequences of simultaneous failure of more than one tank should be considered. For instance, if several tanks are located close to each other, a BLEVE of one tank may lead to the failure of several other tanks. If several tanks are located in one bund, the capacity of the bund should be sufficient to contain the liquid of all tanks, otherwise simultaneous failure of more than one tank may lead to a spill outside the bund.

7. Failure frequencies of process and reactor vessels are higher by a factor of 10 than the failure frequencies of pressure vessels. This factor covers the hazards imposed by the chemical process, like runaway reactions unidentified in the analysis of the process. However, the process is assumed to be analysed using methods like HAZOP, "what/if" and checklist analyses and appropriate measures are taken to prevent the hazards identified. A more complete description of analysis methods is given in the "Red Book" [CPR12E].

8. Catastrophic failure of a gas cylinder does not generally lead to lethal effects outside the establishment. However, the possibility of domino effects should be considered, e.g. following catastrophic failure of a gas cylinder with acetylene. The frequency of catastrophic failure of a gas cylinder (instantaneous release) is 1×10^{-6} per year.

3.2.2 Stationary atmospheric tanks and vessels

The various types of stationary tanks and vessels can be distinguished as given below:

Single-containment atmospheric tank
A single-containment atmospheric tank consists of a primary container for the liquid. An outer shell is either present, or not, but when present, primarily intended for the retention and protection of insulation. It is not designed to contain liquid in the event of the primary container's failure.

Atmospheric tank with a protective outer shell
An atmospheric tank with a protective outer shell consists of a primary container for the liquid and a protective outer shell. The outer shell is designed to contain the liquid in the event of failure of the primary container but is not designed to contain any vapour. The outer shell is not designed to withstand all possible loads, e.g. explosion (static pressure load of 0.3 bar during 300 ms), penetrating fragments and cold (thermal) load.

Double-containment atmospheric tank
A double-containment atmospheric tank consists of a primary container for the liquid and a secondary container. The secondary container is designed to contain the liquid in the event of failure of the primary container and to withstand all possible loads, like explosion (static pressure load of 0.3 bar during 300 ms), penetrating fragments and cold (thermal) load. The secondary container is not designed to hold any kind of vapour.

Full-containment atmospheric tank

Full-containment atmospheric tank

A full-containment atmospheric tank consists of a primary container for the liquid and a secondary container. The secondary container is designed to contain both the liquid and vapour in the event of failure of the primary container, and to withstand all possible loads, like explosion (static pressure load of 0.3 bar during 300 ms), penetrating fragments and cold. The outer roof is supported by the secondary containment and designed to withstand loads e.g. explosion.

Membrane tank

A membrane tank consists of a primary and a secondary container. The primary container is formed by a non-self-supporting membrane that holds the liquid and its vapour under normal operating conditions. The secondary container is concrete and supports the primary container. The secondary container has the capacity to contain all the liquid and to realise controlled venting of the vapour if the inner tank fails. The outer roof forms an integral part of the secondary containment.

In-ground atmospheric tank

An in-ground atmospheric tank is a storage tank in which the liquid level is at or below ground level.

Mounded atmospheric tank

A mounded atmospheric tank is a storage tank that is completely covered with a layer of soil and in which the liquid level is above ground level.

The LOCs for atmospheric tanks are given in Table 3.4 and the frequencies of these LOCs in Table 3.5.

Table 3.4 LOCs for atmospheric tanks

	LOCs for atmospheric tanks
G.1	Instantaneous release of the complete inventory a directly to the atmosphere b from the primary container into the unimpaired secondary container or outer shell
G.2	Continuous release of the complete inventory in 10 min at a constant rate of release a directly to the atmosphere b from the primary container into the unimpaired secondary container or outer shell
G.3	Continuous release from a hole with an effective diameter of 10 mm a directly to the atmosphere b from the primary container into the unimpaired secondary container or outer shell

Table 3.5 Frequencies of LOCs for atmospheric tanks

Installation (part)	G.1a Instantan. release to atmosphere	G.1b Instantan. release to secondary container	G.2a Continuous 10 min release to atmosphere	G.2b Continuous 10 min release to secondary container	G.3a Continuous ∅10 mm release to atmosphere	G.3b Continuous ∅10 mm release to secondary container
single-containment tank	5×10^{-6} y^{-1}		5×10^{-6} y^{-1}		1×10^{-4} y^{-1}	
tank with a protective outer shell	5×10^{-7} y^{-1}	5×10^{-7} y^{-1}	5×10^{-7} y^{-1}	5×10^{-7} y^{-1}		1×10^{-4} y^{-1}
double containment tank	1.25×10^{-8} y^{-1}	5×10^{-8} y^{-1}	1.25×10^{-8} y^{-1}	5×10^{-8} y^{-1}		1×10^{-4} y^{-1}
full containment tank	1×10^{-8} y^{-1}					
membrane tank	see note 7					
in-ground tank		1×10^{-8} y^{-1}				
mounded tank	1×10^{-8} y^{-1}					

Notes:

1. A vessel or tank consists of the vessel (tank) wall and the welded stumps, mounting plates and instrumentation pipes. The LOCs cover the failure of the tanks and vessels, and the associated instrumentation pipework. The failure of pipes connected to the vessels and tanks should be considered separately (see Section 3.2.3).

2. Tanks can be situated inside or outside a building. The LOCs are not dependent on the situation. Modelling a release inside a building is described in Chapter 4.

3. Storage tanks can be used for storing different substances at different times. If large numbers of different substances are transhipped from an establishment, it is useful to classify the substances and use sample substances for each category in the QRA. A classification method is described in [VVoW95]. It should be noted that if a specific substance constitutes an important part of the total amount transhipped, the substance itself will have to be used in the calculation.

4. A cryogenic tank is an atmospheric tank with a storage temperature below ambient temperature. The LOCs for a cryogenic tank are the LOCs of the corresponding type of atmospheric storage tank.

5. Atmospheric storage tanks may have a pressure just above 1 bar absolute. These tanks should be considered as atmospheric storage tanks. Examples are cryogenic tanks and atmospheric storage tanks with nitrogen blanketing.

6. The potential consequences of simultaneous failure of more than one tank should be considered. For instance, if several tanks are located in one bund, the capacity of the bund should be sufficient to contain the liquid of all tanks, otherwise simultaneous failure of more than one tank may lead to a spill outside the bund.

7. The failure frequency of a membrane tank, determined by the strength of the secondary container, should be estimated case by case using the data on the other types of atmospheric tanks.

8. The liquid level in an in-ground atmospheric tank is at or below ground level. The surrounding soil should be considered as a secondary container; failure of the tank results in flash and pool evaporation only.

3.2.3 Pipes

The LOCs for pipes cover all types of process pipes and inter-unit pipelines above ground of an establishment. The LOCs for transport pipelines underground are given elsewhere. The LOCs for pipes are given in Table 3.6 and LOC frequencies for pipes in Table 3.7.

Table 3.6 LOCs for pipes

LOCs for pipes	
G.1	Full bore rupture - outflow is from both sides of the full bore rupture
G.2	Leak - outflow is from a leak with an effective diameter of 10% of the nominal diameter, a maximum of 50 mm

Table 3.7 Frequencies of LOCs for pipes

Installation (part)	G.1 Full bore rupture	G.2 Leak
pipeline, nominal diameter < 75 mm	1×10^{-6} m^{-1} y^{-1}	5×10^{-6} m^{-1} y^{-1}
pipeline, 75 mm ≤ nominal diameter ≤ 150 mm	3×10^{-7} m^{-1} y^{-1}	2×10^{-6} m^{-1} y^{-1}
pipeline, nominal diameter > 150 mm	1×10^{-7} m^{-1} y^{-1}	5×10^{-7} m^{-1} y^{-1}

Notes:

1. The figures given for the pipework failure rate are based on process pipework operating in an environment where no excessive vibration, corrosion/erosion or thermal cyclic stresses are expected. If there is a potential risk causing a significant leak, e.g. corrosion, a correction factor of 3 - 10 should be applied, depending on the specific situation.

2. Pipes can be situated inside or outside a building. The LOCs are not dependent on the situation. The modelling of a release inside a building is described in Chapter 4.

3. The location of the full bore rupture can be important to the outflow. If the location is important, at least three full bore ruptures will have to be modelled:
   - upstream, i.e. situated directly at the vessel at the high pressure side with zero pipeline length
   - middle, i.e. situated halfway along the pipeline
   - downstream, i.e. situated directly at the vessel at the low pressure side.

   For short pipelines, less than 20 metres, the location of the full bore rupture is probably not important; modelling one location for the full bore rupture, i.e. upstream, will suffice. For the leak LOC the location of the leak is probably not that important to the outflow, so that one location for the leak will suffice.

4. For long pipelines, failure locations have to be selected at regular distances to produce a smooth risk contour. There should be enough locations to ensure that the risk contour does not change substantially when the number of failure locations is increased. A reasonable initial distance between two failure locations is 50 metres.

5. Failures of flanges are assumed to be included in the failure frequency of the pipeline; for that reason, the minimum length of a pipe is set at 10 metres.

3.2.4 Pumps

The LOCs for pumps are given in Table 3.8 and the LOCs frequencies for pumps in Table 3.9.

Table 3.8 LOCs for pumps

LOCs for pumps	
G.1	Catastrophic failure - full bore rupture of the largest connecting pipeline
G.2	Leak - outflow is from a leak with an effective diameter of 10% of the nominal diameter of the largest connecting pipeline, with a maximum of 50 mm

Table 3.9 Frequencies for pumps

Installation (part)	G.1 Catastrophic failure	G.2 Leak
pumps without additional provisions	1×10^{-4} y^{-1}	5×10^{-4} y^{-1}
pumps with a wrought steel containment	5×10^{-5} y^{-1}	2.5×10^{-4} y^{-1}
canned pumps	1×10^{-5} y^{-1}	5×10^{-5} y^{-1}

3.2.5 Heat exchangers

The LOCs for heat exchangers are given in Table 3.10 and LOCs frequencies for heat exchangers in Table 3.11. Three different types of heat exchangers are:

- heat exchangers where the dangerous substance is outside the pipes.
- heat exchangers where the dangerous substance is inside the pipes, with the outer shell having a design pressure higher than or equal to the maximum occurring pressure of the dangerous substance inside the pipes
- heat exchangers where the dangerous substance is inside the pipes, with the outer shell having a design pressure less than the maximum occurring pressure of the dangerous substance inside the pipes

Table 3.10 LOCs for heat exchangers

	LOC for heat exchangers
G.1	Instantaneous release of the complete inventory
G.2	Continuous release of the complete inventory in 10 min at a constant rate of release
G.3	Continuous release from a hole with an effective diameter of 10 mm
G.4	Full bore rupture of ten pipes simultaneously - outflow from both sides of the full bore rupture
G.5	Full bore rupture of one pipe - outflow from both sides of the full bore rupture
G.6	Leak - outflow from a leak with an effective diameter of 10% of the nominal diameter, with a maximum of 50 mm

Table 3.11 Frequencies of LOCs for heat exchangers

Installation (part)	G.1 Instantaneous	G.2 Continuous, 10 min	G.3 Continuous, ∅10 mm
heat exchanger, dangerous substance outside pipes	5×10^{-5} y^{-1}	5×10^{-5} y^{-1}	1×10^{-3} y^{-1}
Installation (part)	**G.4 Rupture, 10 pipes**	**G.5 Rupture, 1 pipe**	**G.6 Leak**
heat exchanger, dangerous substance inside pipes, design pressure outer shell less than pressure of dangerous substance	1×10^{-5} y^{-1}	1×10^{-3} y^{-1}	1×10^{-2} y^{-1}
heat exchanger, dangerous substance inside pipes, design pressure outer shell more than pressure of dangerous substance	1×10^{-6} y^{-1}		

Note:

1. The releases are directly into the atmosphere. It is assumed that a contamination of the cooling substance does not lead to external safety effects. If the heat exchanger is equipped with safety devices, like a pressure relief valve, the operation of the safety equipment should be considered in the determination of the outflow.

2. The outflow of the connecting pipelines should be considered as well.

3.2.6 Pressure relief devices

The opening of a pressure relief device results in an emission only if the device is in direct contact with the substance and discharges directly to the atmosphere.

The LOC for pressure relief devices is given in Table 3.12 and LOCs frequency for pressure devices in Table 3.13.

Table 3.12 LOCs for pressure relief devices

	LOC for pressure relief devices
G.1	discharge of a pressure relief device with maximum discharge rate

Table 3.13 Frequency of LOC for pressure relief devices

Installation (part)	G.1 discharge
pressure relief device	2×10^{-5} y^{-1}

3.2.7 LOCs for storage in warehouses

The LOCs for the storage of substances in warehouses concern both the handling of packaging units and the possibility of fire in the warehouse.

These LOCs for the storage of substances in warehouses are given in Table 3.14 and the LOC frequencies in Table 3.15. Both LOCs and calculation methods are described in more detail in [CPR15].

Table 3.14 LOCs for the storage of substances in warehouses

LOCs for the storage of substances in warehouses	
G.1	Handling solids: dispersion of a fraction of the packaging unit inventory as respirable powder
G.2	Handling liquids: spill of the complete packaging unit inventory
S.1	Emission of unburned toxics and toxics produced in the fire

Table 3.15 Frequencies of LOCs for the storage of substances in warehouses

Installation (part)	G.1 Dispersion of respirable powder	G.2 Liquid spill	S.1 Fire
storage of substances in warehouses with protection levels 1 and 2	1×10^{-5} per handling of packaging unit	1×10^{-5} per handling of packaging unit	8.8×10^{-4} y^{-1}
storage of substances in warehouses with protection level 3	1×10^{-5} per handling of packaging unit	1×10^{-5} per handling of packaging unit	1.8×10^{-4} y^{-1}

3.2.8 Storage of explosives

The LOCs for the storage of explosives are given in Table 3.16 and LOC frequencies for this storage in Table 3.17.

Table 3.16 LOCs for the storage of explosives

LOCs for the storage of substances in warehouses	
G.1	mass detonation in a storage unit
G.2	fire in a storage unit

Table 3.17 Frequencies of LOCs for the storage of explosives

Installation (part)	G.1 Mass detonation	G.2 Fire
storage of explosives	1×10^{-5} per year	see note 1

Notes:

1. If a detonation occurs in a storage unit, the LOC should be modelled as mass detonation in a storage unit. If detonation is excluded, the LOC should be modelled as fire in a storage unit.

2. The probability and effects of sympathetic detonation and spread of fire have to be considered.

3. The calculation methods to assess the risks of explosive storage are described in the following references:
   - Manual of NATO safety principles for the storage of military ammunition and explosives (AC258), Allied Ammunition Storage and Transport Publication 1 (AASTP-1), May 1992 [NATO92]. Relevant sections are ‘Internal Safety’ (I-A-3 to I-A-24), ‘Air Blast’ (II-5-15 to II-5-34) and ‘Thermal Radiation’ (II-5-35 to II-5-40).
   - Committee for the Prevention of Disasters. Methods for the calculation of damage (the ‘Green Book’). Voorburg: Ministry of Social Affairs and Employment, 1990[1] [CPR16].
   - Timmers, PGJ. Berekening van het in- en extern risico van explosievenopslag met behulp van ‘RISKANAL’(Draft). Rijswijk: TNO, 1997 [Ti97].

   The relevant sections of the NATO Manual AC258 are available for perusal at the Prins Maurits Laboratory, TNO, Rijswijk. A copy of the relevant sections may be obtained under certain conditions.

3.2.9 Transport units in an establishment

Transport units for loading and unloading activities may be present in an establishment. The LOCs can be divided into: LOCs to cover the intrinsic failure of the transport unit, LOCs to cover loading and unloading activities and LOCs to cover external impact due to accidents.

3.2.9.1 Road tankers and tank wagons in an establishment

The LOCs for road tankers and tank wagons in an establishment are given in Table 3.18 and frequencies of these LOCs in Table 3.19. A distinction is made between atmospheric and pressurised tanks.

Table 3.18 LOCs for road tankers and tank wagons in an establishment

	LOC for road tankers and tank wagons in an establishment
G.1	Instantaneous release of the complete inventory
G.2	Continuous release from a hole the size of the largest connection - If the tank is (partly) filled with liquid, the release is modelled from the liquid phase out of the largest liquid connection.
L.1a	Full bore rupture of the loading/unloading hose - The outflow is from both sides of the full bore rupture.
L.2a	Leak of the loading/unloading hose - The outflow is from a leak with an effective diameter of 10% of the nominal diameter, with a maximum of 50 mm.
L.1b	Full bore rupture of the loading/unloading arm - Outflow from both sides of the full bore rupture
L.2b	Leak of the loading/unloading arm - Outflow from a leak with an effective diameter of 10% of the nominal diameter, with a maximum of 50 mm
E.1	External impact
S.1	Fire under tank - to be modelled as an instantaneous release of the complete inventory of the tank

Table 3.19 Frequencies of LOCs for road tankers and tank wagons in an establishment

	G.1 Instantant.	G.2 Cont, large conn.	L.1a Full bore hose	L.2a Leak hose	L.1b Full bore arm	L.2b Leak arm	E.1 Extern. impact	S.1 Fire
tank, pressurised	5×10^{-7} y^{-1}	5×10^{-7} y^{-1}	4×10^{-6} h^{-1}	4×10^{-5} h^{-1}	3×10^{-8} h^{-1}	3×10^{-7} h^{-1}	see note 1	see note 2
tank, atmospheric	1×10^{-5} y^{-1}	5×10^{-7} y^{-1}	4×10^{-6} h^{-1}	4×10^{-5} h^{-1}	3×10^{-8} h^{-1}	3×10^{-7} h^{-1}	see note 1	see note 2

Notes:

1. The external impact LOCs for road tanker or tank wagon accidents in an establishment are determined by the local situation. A calculation method is described elsewhere in this report. In general, the LOCs for road tanker accidents do not have to be considered in an establishment if measures have been taken to reduce road accidents, like speed limits.

2. Fire under a tank may lead to the instantaneous release of the complete inventory of the tank. Various causes of failure may lead to a fire under a tank:
   - leakage of the connections under the tank followed by ignition. This event only occurs for tanks loaded with flammable substances. The frequency is equal to 1×10^{-6} per year for pressurised tanks and 1×10^{-5} per year for atmospheric tanks.
   - fire in the surroundings of the tank. The failure frequency is determined by the local situation. Important aspects are the presence of tanks with flammable substances nearby and failure during loading and unloading of flammable substances. A calculation method to determine the failure frequency due to the presence of tanks with flammable substances nearby is described elsewhere in this report.

3. LOCs are described here for transport units with large containers. Substances are also transported in small packaging units like gas cylinders. LOCs can be considered for each packaging unit separately. However, domino effects and the simultaneous failure of more than one packaging unit due to external impact have to be considered.

3.2.9.2 Ships in an establishment

The LOCs for ships in an establishment cover loading and unloading activities, and external impact. The LOCs for ships are given in Table 3.20 and LOC frequencies in Table 3.21.

Table 3.20 LOCs for ships in an establishment

	LOC for ships in an establishment	
L.1	Full bore rupture of the loading/unloading arm - outflow from both sides of the full bore rupture	
L.2	Leak of the loading/unloading arm - outflow from a leak with an effective diameter equal to 10% of the nominal diameter, with a maximum of 50 mm	
E.1	External impact, large spill	
	- gas tanker	continuous release of 180 m^3 in 1800 s
	- semi-gas tanker (refrigerated)	continuous release of 126 m^3 in 1800 s
	- single-walled liquid tanker	continuous release of 75 m^3 in 1800 s
	- double-walled liquid tanker	continuous release of 75 m^3 in 1800 s
E.2	External impact, small spill	
	- gas tanker	continuous release of 90 m^3 in 1800 s
	- semi-gas tanker (refrigerated)	continuous release of 32 m^3 in 1800 s
	- single-walled liquid tanker	continuous release of 30 m^3 in 1800 s
	- double-walled liquid tanker	continuous release of 20 m^3 in 1800 s

Table 3.21 Frequencies of LOCs for ships in an establishment

Ship	L.1 Full bore arm	L.2 Leak arm	E.1 External large spill	E.2 External small spill
single-walled liquid tanker	6×10^{-5} per transhipment	6×10^{-4} per transhipment	$0.1 \times f_0$	$0.2 \times f_0$
double-walled liquid tanker	6×10^{-5} per transhipment	6×10^{-4} per transhipment	$0.006 \times f_0$	$0.0015 \times f_0$
gas tanker, semi-gas tanker	6×10^{-5} per transhipment	6×10^{-4} per transhipment	$0.025 \times f_0$	$0.00012 \times f_0$

* The base accident failure rate, f_0, is equal to $6.7 \times 10^{-11} \times T \times t \times N$, where T is the total number of ships per year on the transport route or in the harbour, t the average duration of loading/unloading per ship (in hours) and N, the number of transhipments per year (see note 1).

Notes:

1. The external impact LOCs for collision accidents of a ship are determined by the local situation. If a ship is docked in a (small) harbour outside the transport routes, external-impact LOCs do not have to be considered. However, if movement of ships near the ship docked at the establishment is possible, collision LOCs do have to be considered. The external-impact LOCs are calculated using the base accident rate, f_0. The base accident

failure rate, f_0, is equal to $6.7 \times 10^{-11} \times T \times t \times N$, where T is the total number of ships per year on the transport route or in the harbour, t the average duration of loading/unloading per ship (in hours) and N, the number of transhipments per year.

2. If a loading arm contains more than one pipe, a rupture of a loading arm corresponds to a rupture of all pipes simultaneously.

Appendix 3.A Commentary

3.A.1 LOCs to be included in the QRA

Only LOCs that contribute to the individual and/or societal risk should be included in the QRA under the conditions that (1) the frequency of occurrence is equal to or greater than 10^{-8} per year and that (2) lethal damage (1% probability) occurs outside the establishment's boundary or the transport route. The conditions are taken from [IPO] with the exception of one change. In [IPO] LOCs have to be included if the failure frequency is greater than 10^{-8} per year and if lethal damage (1%) in a residential area is possible. Consequently, the individual risk contours will depend on the location of the residential areas. In an extreme case, if no residential areas are located near the establishment, a risk contour is not necessarily calculated. The criterion therefore becomes: LOCs should be included if the failure frequency is greater than 10^{-8} per year and if lethal damage (1% probability) outside the establishment's boundary is possible. This criterion corresponds with present-day practice. A threshold of 10^{-8} per year as criterion for including LOCs is considered reasonable since generic LOCs leading to the release of the complete inventory have failure frequencies in the range 10^{-5} to 10^{-7} per year.

3.A.2 Failure data

3.A.2.1 General

The failure data given in this Section are copied from [IPO] unless otherwise indicated.

The failure data in [IPO] are largely based on the research done in the COVO study [COVO81]. Meanwhile, a number of review studies published [e.g. AM94, TNO98b, Ta98] show a tendency for some systems towards higher failure frequencies than the ones reported here. However, an update of the failure frequencies would require an extensive investigation into the original data sources to determine the validity of the data and their applicability to current-day practice. Since this investigation has not yet been accomplished, it was decided not to update the failure frequencies in this document. Such an investigation, resulting in an update of the failure frequencies, is anticipated in due time.

The failure frequencies given here do not take the quality of the management explicitly into account. Various (international) projects have been initiated to assess the management system of an establishment and to evaluate the quality of the management by applying management factors to the failure frequencies. However, these projects have not resulted to date in a consistent method to evaluate the management system; consequently, management factors are not introduced in this document. The subject will be considered again with the update of the failure frequencies.

3.A.2.2 Pressure vessels

The failure frequencies of pressure vessels determined in the COVO study are based on data collected by Phillips and Warwick, Smith and Warwick, and Bush [COVO81, Ph69, Sm74, Bu75]. The base failure rate of catastrophic rupture of a pressure vessel is set at 1×10^{-6} per year and is applicable to static, vibration free, pressure vessels operating under conditions of no

corrosion (external or internal) and thermal cycling, i.e. typical storage pressure vessels. The base failure rate of catastrophic rupture of process vessels and reactor vessels is assumed to be ten times higher, i.e. 1×10^{-5} per year. The failure rate of small leaks (a hole with an effective diameter of 10 mm) is assumed to be ten times higher than the catastrophic failure rate.
An instantaneous release is not always found to lead to maximum effect distances. Hence, catastrophic rupture is modelled partly as a continuous release of the complete inventory within ten minutes. This LOC was previously defined as a release from a hole with an effective diameter of 50 mm or, if the duration of this release exceeds ten minutes, a continuous release with a duration of ten minutes [IPO]. For simplicity, the LOC is now defined as a release of the complete inventory in ten minutes at a constant rate of release.

Previously, an LOC ‘Serious leakage from a hole with an effective diameter of 50 mm’ with a failure frequency of 1×10^{-5} per year was defined in the COVO study and the IPO document of 1994 [COVO81, IPO]. This LOC was meant to cover the rupture of pipes connected to the vessel. However, rupture of pipes is already covered by the LOCs of pipes (see Section 3.2.3). To avoid double counting, the LOC ‘Serious leakage from a hole with an effective diameter of 50 mm’ is left out (see also the corrections from RE-95 to the IPO document [IPO]).

The frequency of catastrophic rupture of a gas cylinder is set equal to the catastrophic failure frequency of a pressure vessel. This frequency is in good agreement with the failure frequency of explosion of a gas cylinder (i.e. 9×10^{-7} per year) as reported in [AM94].

3.A.2.3 Atmospheric tanks

The failure frequencies of atmospheric tanks are based on expert judgement. The base failure rate of catastrophic rupture of a single containment atmospheric tank is assumed to be ten times higher than the base failure rate of catastrophic rupture of a storage pressure vessel, i.e. 1×10^{-5} per year. The failure rate of small leaks (a hole with an effective diameter of 10 mm) is assumed to be ten times higher than the catastrophic failure rate.

The effect of the various protection levels are weighed in the base failure rate of catastrophic rupture.

- The base failure rate of an atmospheric tank with a protective outer shell is assumed to be a factor five less than the base failure rate of a single containment atmospheric tank, i.e. 2×10^{-6} per year. It is assumed that in 50% of the catastrophic failures the protective outer shell remains unimpaired and the release is into the unimpaired protective outer shell (failure frequency 1×10^{-6} per year). In the other 50% of the catastrophic failures, the protective outer shell also fails and the release is directly to the environment (failure frequency 1×10^{-6} per year).
- The base failure rate of a double containment atmospheric tank is assumed to be a factor of 80 less than the base failure rate of a single containment atmospheric tank, i.e. 1.25×10^{-7} per year. It is assumed that in 80% of the catastrophic failures, the secondary container remains unimpaired and the release is into the unimpaired secondary container (failure frequency 1×10^{-7} per year). In the other 20% of the catastrophic failures, the secondary container also fails and the release is directly to the environment (failure frequency 2.5×10^{-8} per year).
- The base failure rate of a full containment atmospheric tank (catastrophic failure of both inner and outer containers) is assumed to be 1×10^{-8} per year. Catastrophic failure of the inner tank only does not lead to a release into the environment and is omitted here.

- The base failure rate of an in-ground atmospheric tank or a mounded atmospheric tank is assumed to be equal to the base failure rate of a full-containment atmospheric tank, i.e 1×10^{-8} per year. Failure of an in-ground atmospheric tank leads to pool evaporation only, whereas failure of a mounded atmospheric tank leads to a release directly into the atmosphere.

The failure rate of small leaks of the primary container (a hole with an effective diameter equal to 10 mm) is assumed not to be influenced by the level of protection and is equal to 1×10^{-4} per year for all types of atmospheric tanks. However, small leaks of the primary container of a full containment tank, a membrane tank, an in-ground tank and a mounded tank are assumed not to result in release to the atmosphere and are thus omitted.

Similar to pressure vessels, catastrophic rupture is modelled partly as an instantaneous release and partly as a continuous release within ten min. The subdivision does not apply if the base failure rate of catastrophic rupture is equal to 1×10^{-8} per year since the minimum frequency of LOCs to be considered is equal to 1×10^{-8} per year.

A tank roof collapse of cryogenic storage tanks leads to fragments of the roof falling into the containment. The extra heat input results in an additional evaporation of the refrigerated substance. This process is difficult to model and therefore usually not included in the QRA.

3.A.2.4 Pipes

The failure frequencies of pipes, copied from [IPO], are based on the COVO study [COVO81, AEC75, SRS, Ph69, Sm74] and [Hu92].

The failure frequencies of catastrophic rupture of piping are given in the COVO study as:

- diameter ≤ 50 mm failure frequency 1×10^{-10} m^{-1} h^{-1} = 8.8×10^{-7} m^{-1} y^{-1}
- 50 < diameter ≤ 150 mm failure frequency 3×10^{-11} m^{-1} h^{-1} = 2.6×10^{-7} m^{-1} y^{-1}
- diameter > 150 mm failure frequency 1×10^{-11} m^{-1} h^{-1} = 8.8×10^{-8} m^{-1} y^{-1}

The failure frequency of pipe rupture is given in [Hu92] as a function of the pipe diameter for pipe diameters in the range of 50 - 250 mm:

- ^{10}log (failure rate per metre per year) = $-$ (0.0064 × (pipe diameter in mm) + 5.56).

Note that the relation deviates from the line shown in the corresponding figure [IPO, Hu92]. Using this relation yields the following failure frequencies of pipe rupture:

- diameter 50 mm failure frequency 1.3×10^{-6} m^{-1} y^{-1}
- diameter 75 mm failure frequency 9.1×10^{-7} m^{-1} y^{-1}
- diameter 150 mm failure frequency 3.0×10^{-7} m^{-1} y^{-1}
- diameter 250 mm failure frequency 6.9×10^{-8} m^{-1} y^{-1}

The failure frequencies of catastrophic rupture of piping, copied from [IPO], therefore corresponds to the failure frequencies used in the COVO study. The lower limit of the pipe diameter classification is changed to 75 mm to agree with the failure frequencies given in [Hu92].

The COVO study yields the following figures for significant leakage (hole size between 5 - 15 mm depending on the pipeline diameter):

- diameter ≤ 50 mm failure frequency leak = 10 × failure frequency rupture
- 50 < diameter ≤ 150 mm failure frequency leak = 20 × failure frequency rupture
- diameter > 150 mm failure frequency leak = 30 × failure frequency rupture

The failure frequency of a leak is given in [Hu92] as a function of the hole diameter:

- $^{10}\log$ (failure rate per metre per year) = $-(0.026 \times$ [hole diameter in mm] $+ 5.32)$

If the hole diameter is set equal to 10% of the pipe diameter, the failure frequency of a leak corresponds to:

- diameter 50 mm failure frequency leak = 2.7 × failure frequency rupture
- diameter 75 mm failure frequency leak = 3.3 × failure frequency rupture
- diameter 150 mm failure frequency leak = 6.5 × failure frequency rupture
- diameter 250 mm failure frequency leak = 15.5 × failure frequency rupture

The failure frequencies of a leak (effective diameter leak equal to 0.1 × pipe diameter) are assumed to be five times higher than the failure frequencies of catastrophic rupture [IPO]. This is in reasonable agreement with the data in [Hu92].

3.A.2.5 Pumps

Pumps are not explicitly described in [IPO]. The COVO study gives 1×10^{-4} per year as a frequency of catastrophic failure of a pump [COVO81, SA75, SRS]. This failure frequency is now used for pumps without additional provisions. Provisions are evaluated by expert judgement.

The failure frequencies are averages, irrespective of pump type, type of drive, type of sealing, number of revolutions, etc.

The catastrophic failure is modelled as a full bore rupture of the largest connecting pipeline. Parallel to pipelines, a LOC 'leak' is defined with a failure frequency equal to five times the failure frequency of catastrophic failure.

3.A.2.6 Heat exchangers

Heat exchangers are not listed in [IPO]. The failure frequencies of heat exchangers listed here are based on expert judgement only.

Similar to pressure vessels, catastrophic rupture of a heat exchanger with the dangerous substance outside the pipes is modelled partly as an instantaneous release and partly as a continuous release of the complete inventory within 10 minutes.

For heat exchangers with the dangerous substance inside the pipes, a rupture of 10 pipes is assumed to always go simultaneously with failure of the outer shell and therefore results in a direct release to the environment.

If the design pressure of the outer shell is higher than the maximum occurring pressure of the dangerous substance in the pipes, rupture of one pipe and a leak is assumed not to lead to emission outside the outer shell. Furthermore, a lower failure frequency is used to evaluate the protective effect of the outer shell.

3.A.2.7 *Pressure relief devices*

The LOC describes the opening of a pressure relief device and is based on expert judgement only [IPO].

3.A.2.8 *Storage*

LOCs for the storage of substances in warehouses and their frequencies are copied from [CPR15].

The LOCs for the storage of explosives are based on the present-day risk analysis method.

3.A.2.9 *Transport units in an establishment*

The LOCs for the intrinsic failure of a road tanker or tank wagon in an establishment are based on expert judgement.

Catastrophic failure of a tank is modelled as an instantaneous release of the complete inventory. Unlike stationary vessels, the LOC of catastrophic failure is not subdivided into a instantaneous release and a continuous release within 10 minutes, since a continuous release is already modelled as a release from a hole with the size of the largest connection.

The frequency of catastrophic failure of a pressurised tank is equal to 5×10^{-7} per year. This frequency represents a factor 2 less than the catastrophic failure frequency of a stationary pressure vessel. It is therefore apparently assumed that the different conditions for road tankers and tank wagons, e.g. the possibility of fatigue due to vibrations, are more than compensated by measures taken in the construction of the tanks.

The frequency of catastrophic failure of an atmospheric tank is equal to 1×10^{-5} per year. This frequency is equal to the catastrophic failure frequency of a stationary single-containment atmospheric tank. It is therefore apparently assumed that the different conditions for road tankers and tank wagons, e.g. the possibility of fatigue due to vibrations, are compensated by measures taken in the construction of the tanks.

The LOC ‘Continuous release from a hole the size of the largest connection’ covers the failure of connections at the tank and has a failure frequency of 5×10^{-7} per year. The reasoning behind this value is unknown.

If the tank is loaded with flammable materials, an additional LOC, S.1, is defined to cover a catastrophic failure following leakage and ignition of the flammable substance. The overall failure frequency of flammable material leakage, followed by ignition and in turn followed by an instantaneous release of the complete inventory is set equal to 1×10^{-6} per year for pressurised tanks and 1×10^{-5} per year for atmospheric tanks.

The frequency of catastrophic rupture of a loading arm or loading hose (road tankers and tank wagons) is derived from the COVO study [COVO81, AEC75, We76, Ja71]. In this, the frequency value for a lightly stressed hose is used; the frequency of a rupture of a heavily stressed hose is a factor 10 higher. The frequency of a leak is assumed to be 10 × the frequency of catastrophic rupture.

The failure frequencies of the LOCs for ships at an establishment are derived from [KO 22-5] and [IPORBM]. The failure frequency of external impact is based on a number of accidents involving bunker ships, leading to heavy damage. The derivation is described in [KO22-5]. The LOCs associated with external impact are copied from [IPORBM].

The failure frequency during loading and unloading of ships is based on the number of spills in the harbour of Rotterdam in the period 1976 - 1988, leading to a spill frequency of 6.7×10^{-4} per handled ship [KO 22-5]. The frequency of a leak is assumed to be 10 × the failure frequency of a rupture, leading to a frequency of rupture of 6×10^{-5} per transhipment and a frequency of leakage of 6×10^{-4} per transhipment.

4. MODELLING SOURCE TERM AND DISPERSION

4.1 Introduction

After defining the loss of containment events, as described in Chapter 3, for a situation, the source term and the dispersion in the environment will have to be calculated.

Models to calculate source term and dispersion are described extensively in the ‘Yellow Book’ [CPR14E] and in the risk analysis method for warehouses [CPR15]. Various types of models like the following, are described:

- outflow and spray release
- pool evaporation
- vapour cloud dispersion
  - jets and plumes
  - dense gas dispersion
  - passive dispersion
- vapour cloud explosion
- heat flux from fires
- rupture of vessels

The models described in the ‘Yellow Book’ are selected to combine good scientific performance with ease of application in practice. For this reason these models are recommended for the QRA calculations.

In the Netherlands, several integrated software packages are commonly used to assess the risks associated with the storage, processing and transport of dangerous substances. In addition, more complex models may be preferred for obtaining reliable results in specific situations. Consequently, other models can be used for the QRA calculations besides those described in the ‘Yellow Book’. However, the user should demonstrate adequate scientific performance in applying the models. The scientific performance of the models should be demonstrated using the results of validation exercises, model intercomparison studies and/or publications.

The models to be used in the QRA have already described elsewhere in detail [CPR14E]. For each loss of containment event, an appropriate outflow model has to be selected. Next, various parameters have to be set in the model calculation. This chapter describes the connection between the loss of containment situations, as described in Chapter 3, and the models to calculate the outflow and the dispersion in the environment. Subsequently, a number of recommended parameter values are described.

It should be noted that plant-specific information should be used whenever possible. If plant-specific information is not available, use can be made of the generic values given here.

4.2 Properties of substances

To calculate the source term and the dispersion of substances in the environment, the (temperature-dependent) physical properties of the substances are needed. Information on the physical properties can be found in a number of references and databases. Examples are:
- The ‘Yellow Book’ [CPR14E];
- The DIPPR database [DIPPR];
- Perry *et al.* [Pe84];
- Reid *et al.* [Re88];
- Yaws [Ya77].

4.3 Outflow models

Chapter 2 describes the loss of containment events (LOCs) to be used in the QRA. For each LOC, the outflow of material can be calculated using the models in the ‘Yellow Book’. However, there is still some freedom in the selection of the model to determine the outflow conditions. Table 4.1 gives the correlation between the LOC’s and the models described in the ‘Yellow Book’.

Table 4.1 Correlation between LOC’s and outflow models

Loss of containment	Installation	To model as:
instantaneous	tanks and vessels road tanker tank wagon	totally ruptured vessel - gas: no air entrainment during expansion - liquid: spreading pool
continuous release	tanks and vessels road tanker tank wagon ships	hole in vessel wall (sharp orifice)
full bore rupture	process pipes, transport pipelines, loading- /unloading arm or hose	full bore ruptured pipeline
leak	process pipes, transport pipelines loading- /unloading arm or hose	outflow through small leak (sharp orifice)
emission of unburned toxics and toxics produced in the fire	Warehouses	see [CPR15]
inventory of a packaging unit as respirable powder	Warehouses	see [CPR15]
spill of the complete inventory of a packaging unit	Warehouses	see [CPR15]
pressure relief valve	All	hole in vessel wall (rounded orifice)
pool evaporation	tanks and vessels	pool evaporation
process scenarios	tanks and vessels	specific models
release inside building	pipes, tanks, vessels	see Section 4.6.3

Notes:

1. The ‘Yellow Book’ does not describe a model for a totally ruptured vessel filled with compressed gas and for a totally ruptured vessel filled with (non-boiling) liquid. In the case of a *totally ruptured vessel with compressed gas*, it can be assumed that the initial cloud expands isentropically to atmospheric pressure without entrainment of ambient air. In case of a *totally ruptured vessel with non-boiling liquid*, it can be assumed that the liquid leads to a spreading pool on the ground or water surface, growing from its original size, i.e. of the ruptured vessel.

2. The continuous release from tanks, vessels and transport units is modelled as a hole in the vessel wall with a sharp orifice. If the value of the discharge coefficient, C_d, is not calculated in the model, it should be set at $C_d = 0.62$.

3. A leak in a pipe or loading/unloading arm/hose can be modelled as if a constant pressure upstream is present. If the value of the discharge coefficient, C_d, is not calculated in the model, the value must be set to $C_d = 0.62$.

4. If there is a full bore rupture in a pipeline, the value of the discharge coefficient, C_d, must be set to $C_d = 1.0$ if the value is not calculated in the model.

5. Generic values are used for the pipeline characteristics if no additional information is present, i.e.:
   - no bends in the pipe
   - a pipe wall roughness of 45 μm

6. The discharge rate from a pressure relief valve is determined by the characteristics of the pressure valve and the downstream piping. The discharge rate is set equal to the maximum discharge rate.

7. The release duration is determined by the conditions of the installation and the type of LOC. The release duration can be anywhere from instantaneous to several hours if no counter-measures are taken. In the QRA calculation, the release duration is limited to a maximum of 30 minutes; effects are calculated using only the mass released in the first 30 minutes following the start of the release to the environment.

8. If during normal operation the content of a vessel varies in time, this variation has to be modelled. Discrete values are used for the vessel content and a LOC is subdivided into a number of distinct situations. Each distinct situation is modelled with a specific value of the vessel content. The percentage of occurrence of a specific vessel content is discounted for in the frequency calculation.

9. The presence of pumps in pipelines and their volumetric flow have to be taken into account in the calculation of the outflow. If no pump specifications are available, assuming a release rate of 1.5 times the nominal pumping rate (increase due to loss of pressure head) is suggested.

10. If the discharge is from the liquid section of the vessel, pure liquid is released. Flashing in the hole is not modelled; flashing takes place outside the vessel.

11. The location of the release is determined by the specific situation. For instance, the location of the pressure relief valve determines the location of its release. The outflow of a vessel or tank can be modelled using a distribution of release locations at different heights. The failure frequency of the vessel should then be divided over the various release locations. However, care should be taken that all relevant processes are considered in the outflow calculation, possibly requiring different models for the different release locations. As this may become a time-consuming calculation, the following simplified and more conservative approach may be applied:
    - One single release location is selected. The location of the release is assumed to be one metre above ground level, but the total inventory of the tank or vessel is assumed to be released.
    - If the vessel or tank is (partly) filled with liquid, the release should be modelled from the liquid phase with a liquid head equal to half the maximum liquid head.
    - In process and reactor vessels, various substances can be present under different conditions. For instance, in a distillation column a toxic substance can be present in the gas phase, whereas a flammable solvent can be present in the liquid phase. In this case, at least two release points have to be considered: (1) release of the toxic substance from the gas phase and (2) release of the flammable substance from the liquid phase.

12. The direction of the release is determined by the specific situation. For instance, the outflow of a pressure relief device is generally vertically oriented. If no specific information is available, the direction of the outflow is set horizontal, parallel to the wind direction. An exception to this rule is an underground pipeline, of which the direction of release is vertical.

13. The outflow can be obstructed, for example, by the soil surface and objects in the direct vicinity. The outflow is generally modelled as an unobstructed outflow. Obstruction of the outflow should be modelled if the following two conditions are met:
    1. the ratio L_o/L_j is less than 0.33, with L_o the distance between the release point to the obstacle and L_j the length of the free jet
    2. the probability P_i that the ratio L_o/L_j is less than 0.33 should be larger than 0.5 considering all possible directions of the outflow.

    The length L_j of a free jet of gas can be estimated using the equation:

    $$L_j = 12 \times u_0 \times b_0 / u_{air} \qquad (4.1)$$

    where:

    u_0 velocity of the jet at the source (m s^{-1})
    b_0 source radius (m)
    u_{air} average ambient wind velocity, set equal to 5 m s^{-1}

    If the two conditions are met, an LOC with frequency, *f*, is divided in two separate LOCs:
    - an obstructed outflow with frequency $P_i \times f$
    - an unobstructed outflow with frequency $(1 - P_i) \times f$

The obstructed outflow is modelled as a jet with the impulse reduced by a factor of 4. If the outflow is obstructed by the ground, the release height should be set to 0.

4.4 Repression factors

Repression systems can be present to limit the release of substances into the environment. The effect of repression systems can be taken into account in the QRA. A distinction is made between blocking and other repression systems. In general, the effect of repression systems can only be considered if the effectiveness of the system is demonstrated.

4.4.1 Blocking systems

Blocking systems can be present to limit the outflow once a loss of containment occurs. The operation of blocking valves can be triggered by, for instance, a detection system for gas or the detection of an excess flow. The blocking valves can be closed either automatically or through an operator.

The effect of the blocking system is determined by various factors, such as the position of gas detection monitors and the distribution thereof over the various wind directions, the detection limit of the detection system, the system reaction time and the intervention time of an operator. The effect of the blocking system should be determined in an event tree analysis; here, the failure on demand of the system should be considered. The probability of failure on demand of the system as a whole is about 0.01 per demand.

If the operation of the blocking system is not established through an analysis, default values can be used, which here are to be considered as guidelines. It is assumed that an automatic detection system is present, like a gas detection system of sufficient sensitivity with monitors covering all wind directions. Three different types of blocking systems are distinguished, namely the automatic blocking system, the remote-controlled blocking system and the hand-operated blocking system.

- An automatic blocking system is a system where the detection of the leakage and closure of the blocking valves is fully automatic. There is no action of an operator required.
  - The closing time of the blocking valves is two minutes.
  - The failure upon demand for the blocking system is 0.001 per demand.
- A remote-controlled blocking system is a system where the detection of the leakage is fully automatic. The detection results in a signal in the control room. The operator validates the signal and closes the blocking valves using a switch in the control room.
  - The closing time of the blocking valves is ten minutes.
  - The failure upon demand for the blocking system is 0.01 per demand.
- A hand-operated blocking system is a system where the detection of the leakage is fully automatic. The detection results in a signal in the control room. The operator validates the signal, goes to the location of the blocking valves and closes the valves by hand.
  - The closing time of the blocking valves is 30 minutes.
  - The failure on demand for the blocking system is 0.01 per demand.

4.4.2 Other repression systems

Various repression systems can be installed to limit the effects following a loss of containment. Examples are sprinkler installations to limit the spread of a fire, water shields to prevent the dispersion of (water soluble) substances in the atmosphere and the use of foam to limit pool evaporation.

The effect of a repression system may appear in the QRA calculations on the condition that the effectiveness of the system is ascertained. The reaction time and effectiveness of the system must be demonstrated with, for instance, data from the manufacturer and logbooks of tests and exercises.

The effect of a repression system appears in the QRA using the following method:

1. Determine the time for the system to become effective, $t_{react.}$

2. Determine the effectiveness of the system.

3. Set the source term for the time period 0 to t_{react} equal to the source term without the repression system.

4. Correct the source term for the time period following t_{react} with the effectiveness of the repression system.

5. Take the failure upon demand of the repression system into account. The probability of failure upon demand should be determined with tools like fault tree analysis. A default value is 0.05 per demand.

4.5 Pool evaporation

Pool evaporation models are described in the ‘Yellow Book’. The following points have to be considered:

- The spread of the liquid pool is influenced by obstacles and provisions to discharge the spill. Examples are bunds, inclined surfaces, outlet-pipes to storage tanks or discharge into the sewerage. The presence of these provisions can be taken into account as a loss term for the mass in the liquid pool or as a constraint to the dimensions of the liquid pool. However, the consequences of the discharge of the liquid elsewhere has to be considered.

- If a spill of liquid occurs in a bund, its characteristics have to be taken into account. If the walls of the bund are sufficiently high, the bund prevents the spreading of the liquid pool and the dimensions of the pool are restricted to those of the bund. An effective pool radius, R_{pool}, is then calculated from the bund area, A_{bund}, using the equation:

$$R_{pool} = \sqrt{(A_{bund} / \pi)} \qquad (4.2)$$

- Various physical properties of the soil are needed to calculate the spread of the liquid pool and the pool evaporation. Default values are listed in Table 4.2 for the surface roughness and in Table 4.3 for the thermodynamic properties.

Table 4.2 Characteristic average roughness length of the soil

Soil	Average roughness length (m)
flat sandy soil, concrete, stones, industrial site	0.005
normal sandy soil, gravel, railroad yard	0.010
rough sandy soil, farmland, grassland	0.020
very rough, sandy soil grown over and with potholes	0.025

Table 4.3 Heat conduction properties of various materials: thermal conductivity (λ_s), density (ρ_s), specific heat ($C_{p,s}$) and thermal diffusivity (a_s)

Material	λ_s ($J\ s^{-1}\ m^{-1}\ K^{-1}$)	ρ_s ($kg\ m^{-3}$)	$C_{p,s}$ ($J\ kg^{-1}\ K^{-1}$)	a_s ($m^2\ s^{-1}$)
isolation concrete	0.207	900	920	2.5×10^{-7}
light concrete	0.418	1800	920	2.5×10^{-7}
heavy concrete	1.3	2400	920	5.9×10^{-7}
clinkers	0.7	2000	836	4.2×10^{-7}
average subsoil 8 wt% moist	0.9	2500	836	4.3×10^{-7}
dry sandy subsoil	0.3	1600	799	2.0×10^{-7}
wet sand 8 wt% moist/clay	0.6	1940	937	3.3×10^{-7}
wood	0.2	550	2300	1.6×10^{-7}
gravel	2.5	2000	1140	11.0×10^{-7}
carbon steel	46.0	7840	460	128.0×10^{-7}

4.6 Vapour cloud dispersion

The models for the vapour cloud dispersion are described in the ‘Yellow Book’ [CPR14E].

4.6.1 Coupling outflow and vapour cloud dispersion

The result of the outflow models as defined in Section 4.3 forms the input for the models to calculate the vapour cloud dispersion. Since the outflow models result in a mass flow rate varying in time, the time variation in the source term should be taken into account in the vapour cloud dispersion calculation. Numerical integration methods are to be used as shown in the ‘Yellow Book’ [CPR14E].

The use of numerical integration methods may lead to elaborate and time-consuming calculations. Therefore an approximation may be used in which the outflow is divided into a number of discrete time segments. Next, the dispersion of the various segments has to be calculated using dispersion models. This section gives some guidelines to divide a time-varying source term into discrete time segments and to model the dispersion of the vapour cloud. However, it should be noted that the modelling of the dispersion of time-varying releases is complicated and the rules given here are to be used as guidelines only. For each time-varying source term consideration should be given to what the best solution is.

A time-varying source term can be approximated through a number of discrete time segments with constant outflow conditions by dividing the total mass released evenly over a number of time segments. The outflow conditions in each time segment can be calculated using the following rules:

- Calculate the total mass released in the first 30 min following the LOC, M_{rel}.
- Decide on the number of time segments, N_{seg}. A division into five time segments will suffice in most calculations.
- Divide the total mass released evenly over the time segments, i.e. the mass released in each time segment, M_{seg}, is equal to $M_{seg} = M_{rel} / N_{seg}$.
- Calculate the release duration of the first time segment, $D_{rel.1}$, as the time needed to release a mass M_{seg}.
- Calculate the release rate in the first time segment, $Q_{rel.1}$, as $Q_{rel.1} = M_{seg} / D_{rel.1}$.
- Set the outflow conditions in the first time segment equal to the conditions corresponding with the release rate $Q_{rel.1}$.
- Calculate the release duration, release rate and outflow conditions for the other time segments using the same procedure.

Figure 4.1 shows an example where a time-varying release is approximated with five time segments having equal mass.

It is preferred to use multiple time segments to approximate a time-varying release. However, a time-varying source term can also be approximated with a single time segment having constant outflow conditions, if modelling a single time segment can be shown to give results comparable to a division in five time segments. The outflow conditions in a single time segment can be determined using the following rules:

- For flammables, the outflow conditions are equal to the conditions of the first time segment, having approximated the time-varying release with five time segments. This means that the release rate, Q_{rel}, is equal to 20% of the total mass released, divided by the time needed to release the first 20% of the total mass: $Q_{rel} = 0.2 \times M_{rel} / D_{rel.1}$. The release duration, D_{rel}, is equal to the total mass released, divided by the release rate: $D_{rel} = M_{rel} / Q_{rel}$. The outflow conditions are equal to the conditions corresponding to the release rate Q_{rel}.
- For toxics, the outflow conditions are equal to the conditions of the second time segment, having approximated the time-varying release with five time segments. This means that the release rate, Q_{rel}, is equal to 20% of the total mass released, divided by the time needed to release the second 20% of the total mass: $Q_{rel} = 0.2 \times M_{rel} / D_{rel.2}$. The release duration, D_{rel}, is equal to the total mass released, divided by the release rate: $D_{rel} = M_{rel} / Q_{rel}$. The outflow conditions are equal to the conditions corresponding with the release rate Q_{rel}.

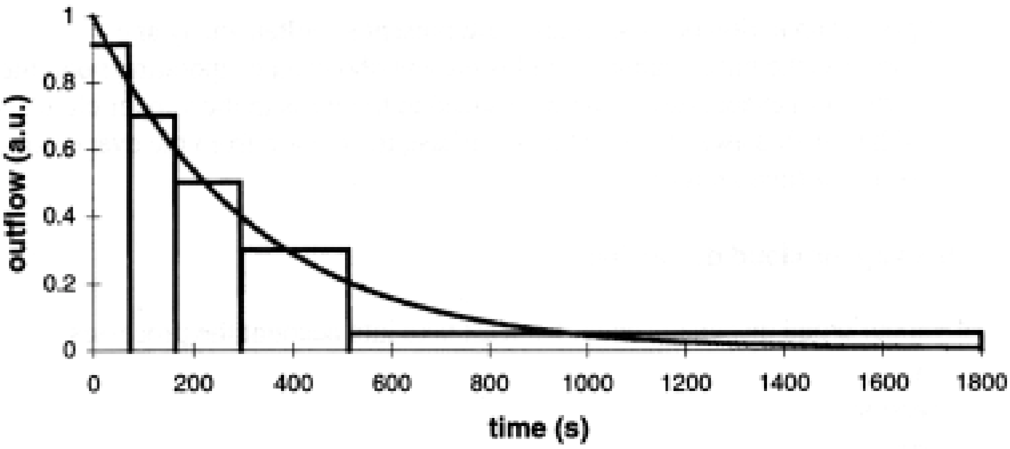

Figure 4.1 Approximation of a time-varying release with five time segments, each of which has constant outflow conditions. The mass released is the same in each time segment.

Calculating the dispersion of various release time segments, originating, for example, from a time-varying release or the release of a vapour cloud combined with pool evaporation, is complicated. During the transport of the mass in the various time segments downwind, the clouds interfere due to down-wind dispersion. In general, two different approaches can be followed:

- Each cloud segment is treated as an independent puff release, not influenced by the leading or trailing cloud segment. Dispersion of the puff occurs during the transport downwind, thus increasing the passage time of the cloud and decreasing the concentration. This approximation is probably suitable if a short-term, high initial release rate is followed by a long-term, small release rate.
- Each cloud segment is treated as an independent steady-state release. Dispersion of the puff downwind does not occur during the transport downwind, and the passage time of the cloud is equal to the release duration of the segment until the total release can be considered as instantaneous. This approximation is probably suitable if the change in release rate between two adjacent time segments is limited.

The toxic dose is calculated as the sum of the toxic doses of each cloud segment. In general, the approximation of a cloud segment as an independent puff will overestimate the dispersion of the actual cloud and thus underestimate the toxic dose received if the dose is more than proportional to the concentration. The approximation of a cloud segment as an independent steady-state release will underestimate the dispersion of the actual cloud and thus overestimate the toxic dose received if the dose is more than proportional to the concentration.

The following guidelines are to be used to model multiple time segments in the release:

1. If two releases are present simultaneously, e.g. releases from both ends of a full pipe rupture, the releases have to be added.

2. If two releases are sequential (e.g. as time segments of a time-varying release or as a cloud from an evaporating pool following the vapour cloud that has drifted away) each cloud segment is treated as an independent steady-state release neglecting the dispersion downwind until the total release can be considered as instantaneous.

3. If rain-out and pool evaporation occurs, releases are present simultaneously and sequentially. As long as the initial vapour cloud is present above an evaporating pool, the mass released in the pool evaporation should be added to the mass in the vapour cloud. As the vapour cloud has drifted away from the pool surface, the release from the evaporating pool is treated as a new time segment.

4.6.2 Modelling the vapour cloud dispersion

The calculation of vapour cloud dispersion should at least take into account the processes:
* jets and plumes
* dense gas dispersion
* passive dispersion

The wet and dry deposition processes can be modelled if the data are available, otherwise the deposition processes do not have to be considered.

Chemical processes in the cloud need to be considered if the hazard of cloud release and dispersion is strongly affected. An example is the release of HF, where the formation of dimers and polymers, and the reaction with water vapour, changes the characteristics of the vapour cloud.

The aerodynamical roughness length is a measure of the influence of the terrain on the cloud dispersion. The use of the roughness length assumes that no large obstacles are present that will affect the dispersion. The roughness length is defined by the terrain upwind. In general, a single average value is used for the surroundings of the installation. Default values are given in Table 4.4.

Large obstacles change the dispersion of a cloud to a large extent, in which case the use of an average roughness length is no longer applicable. The models described in the 'Yellow Book' do not account for the presence of obstacles. Some simple models exist for specific situations [CPR14E]. However, the presence of large objects can only be addressed using complex computer codes, like CFD calculations or wind tunnel experiments. If possible, the influence of large obstacles should be determined quantitatively and be addressed in the QRA. If it is not possible to quantify the influence of large obstacles, a qualitative description is required.

Dispersion models use an averaging time to calculate the maximum concentration and the plume width. The values to be used for the averaging time t_{av} are:
- flammables t_{av} = 20 sec
- toxics t_{av} = 600 sec

Table 4.4 Terrain classification in terms of aerodynamic roughness length, z_0

Class	Short description of terrain	z_0 (m)
1	open water, at least 5 km	0.0002
2	mud flats, snow; no vegetation, no obstacles	0.005
3	open flat terrain; grass, few isolated objects	0.03
4	low crops; occasional large obstacles, x/h > 20 (1)	0.10
5	high crops; scattered large obstacles, 15 < x/h < 20 (1)	0.25
6	parkland, bushes; numerous obstacles, x/h < 15 (1)	0.5
7	regular large obstacle coverage (suburb, forest)	(1.0) (2)
8	city centre with high- and low-rise buildings	(3.0) (2)

(1) *x* is a typical upwind obstacle distance and *h* the height of the corresponding major obstacles.
(2) These values are rough indications. The use of an aerodynamic roughness length, z_0, does not account for the effects of large obstacles.

4.6.3 Release inside a building

Vessels, tanks and pipes can be situated inside a building. Following release, the dispersion of the substances is affected by the building.

The following rules apply:

- If the building is not expected to withstand the pressure load following the release of material, the emission should be considered as entering directly into the atmosphere; the dispersion will then be modelled as if no building is present.

- If the building is expected to withstand the pressure load following the release of material, the source term outside the building is derived from the source term inside the building and the ventilation system. The location of the source is defined by the location of the outlet of the mechanical ventilation and/or the location of the natural ventilation openings.

The release to the atmosphere is determined by the concentration inside the building as a function of time and place. Models can be used to calculate the time- and space-dependent concentration (see, for example, [Gi97]). However, often a more simple approach is used, assuming that the concentration inside the building is uniform and instantaneously in equilibrium with the release from the source. This simplifies the calculation of the release to the atmosphere considerably:

1. For a continuous release, the release to air, Q_{out} (t), is set equal to the source term inside the building, Q_{in} (t). For an instantaneous release, the release to air, Q_{out}, is given by the equation:

$$Q_{out} = M \times F / V; \tag{4.3}$$

where:

Q_{out}	Source strength to the atmosphere	(kg s^{-1})
M	Mass released	(kg)
V	Volume of the room	(m^3)
F	Ventilation rate	(m^3 s^{-1})

The duration of the release, t_{rel}, is equal to M / Q_{out}.

2. The release is to be modelled as a continuous jet in cross wind [CPR14E]. The location of the release is determined by the location of the ventilation opening.

3. If a release occurs within the recirculation zone downwind of the building or from the roof of the building, the influence of the recirculation zone downwind of the building has to be considered. The plume is entirely taken up in the lee and the concentration in the recirculation zone can be expressed as:

$$C_{rz} = Q_{out} / (K \times A \times u); \tag{4.4}$$

C_{rz} Concentration in the recirculation zone(kg m^{-3})
Q_{out} Source strength to the atmosphere (kg s^{-1})
K Parameter to account for the building shape and orientation (-)
A Projection of the building in wind direction (m^2)
u Wind speed at the height of the building (m s^{-1})

The parameter K depends on the shape and orientation of the building relative to the wind direction and values of K range from K = 0.1 to K = 2. A default value of K = 1 can be assumed in combination with an average projection of the building in the wind direction.

The length of the recirculation zone is assumed to be equal to three times the minimum of either the width or the height of the building. To determine the concentration outside the recirculation zone, a virtual source technique can be used, matching the concentration at the end of the lee.

In case of a vertical release from a chimney at the top of the building, the influence of the recirculation zone downwind of the building has to be considered. The uptake in the lee is modelled in terms of a lowering of the release height and a change in the dispersion coefficients. The model is described in [NNM98].

Note:

1. The modelling of a fire in a building equipped with smoke shutters is similar to the modelling of warehouse fires (see Section 4.6.4). As long as the building is intact, the toxic substances are assumed to be homogeneously mixed inside the building. The release is out of the smoke shutters with atmospheric pressure and zero heat content. The effect of the building wake on the release has to be considered. Once the building is no longer intact, it is assumed that plume rise occurs and lethal effects are not expected anymore.

4.6.4 Fires and plume rise

In a fire, unburned toxics and toxic combustion products can be released to the environment. Due to the high temperature of the cloud, the cloud will rise. The consequences of plume rise have to be considered in the QRA.

- In the case of fires within buildings, like CPR-15 storages, no plume rise is assumed to occur during the first stage of the fire since the building is still intact and the building lowers the temperature of the combustion products. After the first stage, plume rise occurs and calculation is terminated as lethal effects are no longer expected [CPR15].
- In the case of open fires, plume rise is assumed to occur immediately and no lethal effects are expected.

4.7 Ignition

4.7.1 Direct ignition

The probability of direct ignition for stationary installations is given in Table 4.5 and for transport units at an establishment in Table 4.6. For stationary installations, a division is made into K1-liquid, low reactive gas and average/high reactive gas. The reactivity is listed in Table 4.7 for a number of substances.

Table 4.5 Probability of direct ignition for stationary installations

Source		Substance		
Continuous	Instantaneous	K1-liquid	Gas, low reactive	Gas, average/high reactive
< 10 kg/s	< 1000 kg	0.065	0.02	0.2
10 - 100 kg/s	1000 - 10,000 kg	0.065	0.04	0.5
> 100 kg/s	> 10,000 kg	0.065	0.09	0.7

Table 4.6 Probability of direct ignition for transport units in an establishment

Source	Probability of direct ignition
road tanker continuous	0.1
road tanker instantaneous	0.4
tank wagon continuous	0.1
tank wagon instantaneous	0.8

*Table 4.7 Reactivity of a number of substances ([CPR14]). If little or no information is available, substances are classified as high reactive. These substances are indicated with an *.*

Low	Average	High (1)
1-chloro-2,3-epoxypropane 1,3-dichloropropene	1-butene	1-butanethiol*
3-chloro-1-propene	1,2-diaminoethane	acetylene
ammonia	1,3-butadiene	benzene*
bromomethane	acetaldehyde	carbon disulfide*
carbon monoxide	acetonitrile	ethanethiol*
chloroethane	acrylonitril	ethylene oxide
chloromethane	butane	ethylformate*
methane	chloroethene	formaldehyde*
tetraethyl lead	dimethylamine	hydrogensulfide*
	ethane	methylacrylate*
	ethene	methylformate*
	ethylethanamine	methyloxirane*
	formic acid	naphtha, solvent*
	propane	tetrahydrothiophene*
	propene	vinylacetate*

Given an instantaneous release with direct ignition, a BLEVE and a fire ball may occur. The probability of a BLEVE and fire ball, P_{BLEVE}, is equal to:

- stationary installations $P_{BLEVE} = 0.7$
- transport units in an establishment $P_{BLEVE} = 1.0$

The mass in the BLEVE is set equal to the total inventory of the tank. The pressure at failure of the vessel should be equal to 1.21 × the opening pressure of the relief device or, if no relief device is present, should be equal to the test pressure of the vessel.

Where no BLEVE and fire ball occur following an instantaneous release with direct ignition, a vapour cloud expanded to atmospheric pressure and a liquid pool are formed. The direct ignition of the vapour cloud is modelled as a flash fire and explosion, as described in Section 4.8. The direct ignition of the liquid pool results in a pool fire. The mass in the vapour cloud depends on the adiabatic flash fraction, χ, and is given by the relations in Table 4.8.

Table 4.8 Mass in vapour cloud following an instantaneous release with direct ignition

adiabatic flash fraction, χ	Mass in vapour cloud (fraction of the total inventory of the tank)
$\chi < 0.1$	$2 \times \chi$
$0.1 \leq \chi < 0.36$	$(0.8 \times \chi - 0.028) / 0.26$
$\chi \geq 0.36$	1

4.7.2 Delayed ignition

To calculate the delayed ignition probability, various rules exist. Two different ways to apply delayed ignition in the QRA calculation are described here, a calculation with actual ignition sources (A) and a free field calculation (B).

A. Calculation with actual ignition sources
A QRA calculation can be done using the specific locations of the known ignition sources at the establishment and outside the establishment. The distribution of ignition sources in the environment should be known or can be anticipated. An overview of ignition sources and their strengths is given in Appendix 4.A. It should be noted that if only a few (weak) ignition sources are present, there is a probability that ignition of the cloud will not occur.

B. Free field calculation
A QRA calculation can be done using the specific locations of the known ignition sources at the establishment. If the cloud is not ignited at the establishment, ignition is assumed to take place at maximum cloud area, with cloud area defined as the surface area of the LFL-footprint of the cloud. If an LFL-contour is not present outside the establishment, e.g. the spill of a flammable liquid in a bund, and if ignition does not occur at the establishment, ignition is assumed not to take place.

The Societal Risk calculation is to be done with calculation method A, the calculation with actual ignition sources.

The Individual Risk calculation is to be done with either calculation method A or calculation method B, to be decided by the competent authorities.

4.7.3 Substances both toxic and flammable

Substances that are both toxic and flammable should in principle be modelled using toxic properties as long as the cloud is not ignited and flammable properties as soon as the cloud ignites. However, this approach is currently too complicated for the models used. The LOC is therefore split into two independent events, namely, a purely flammable event and a purely toxic event.

Substances having a low reactivity (see Table 4.7) are to be modelled as a purely toxic event. Examples are ammonia, carbon monoxide and tetraethyl lead.

Substances having an average or high reactivity (see Table 4.7) are to be modelled using two independent events, namely, a purely flammable event and a purely toxic event. Examples are acrolein, acrylonitril, allylalcohol and ethylene oxide. The probabilities of the flammable event and the toxic event are determined by the probability of direct ignition, $P_{d.i}$. If direct ignition occurs, the event is modelled as a flammable event with probability $P_{d.i}$. If direct ignition does not occur, the event is modelled as a toxic event with probability $(1 - P_{d.i.})$. The toxic event is modelled as if the substance is purely toxic, and the flammable event is modelled as if the substance is purely flammable. To summarise, a LOC with frequency f is divided in two separate events:

- a purely flammable event following direct ignition with frequency $P_{d.i.} \times f$;
- a purely toxic event with frequency $(1 - P_{d.i.}) \times f$.

Values of the probability of direct ignition, $P_{d.i.}$, are given in Table 4.5 and Table *4.6*.

Note:

1. Toxic effects after ignition of the flammable cloud are not considered. It is assumed that after ignition plume rise occurs and toxic effects are no longer expected.

4.8 Effects of ignition of a vapour cloud

Following the ignition of an unconfined vapour cloud, one event occurs with characteristics from both a flash fire and an explosion. This can be assumed to be modelled as two separate events, namely, a pure flash fire and a pure explosion:
- a flash fire with no pressure effects, with a probability of 0.6;
- an explosion, with no flash fire effects, with a probability of 0.4.

The mass in the cloud is equal to the mass within the LFL-contour.

The ‘side-on’ overpressure of the explosion can be calculated using the multi-energy method with the highest value of the blast strength, 10 [CPR14E]. In the calculation, the flammable mass of the cloud has to be partitioned into obstructed regions and non-obstructed regions, and the centre of the explosion has to be determined by the location of the obstructed regions.

Assuming that a fraction f_{obstr} of the total mass in the flammable cloud is in obstructed regions and a fraction $(1 - f_{obstr})$ in non-obstructed regions, the distances to the peak ‘side on’ overpressure contours of 0.3 barg and 0.1 barg, $R_{0.3\ barg}$ and $R_{0.1\ barg}$, respectively, can be calculated as:

$$R_{0.3\ barg} = 1.5 \times (f_{obstr} \times E / P_a)^{1/3} \quad (4.5)$$
$$R_{0.1\ barg} = 3 \times (f_{obstr} \times E / P_a)^{1/3} \quad (4.6)$$

with:

$R_{0.3\ barg}$	distance to the peak ‘side on’ overpressure contour of 0.3 barg(m)
$R_{0.1\ barg}$	distance to the peak ‘side on’ overpressure contour of 0.1 barg(m)
E	combustion energy of the flammable mass within the LEL contour (J)
f_{obstr}	fraction of the total mass in the flammable cloud in obstructed regions (-)
P_a	ambient pressure (N m^{-2})

As default values, the fraction of the mass in obstructed regions, f_{obstr}, can be set equal to 0.08, and the centre of the explosion can be located at the centre of the cloud.

4.9 Rupture of vessels

The rupture of a pressurised vessel leads to the release of the internal energy, besides the release of the vessel contents. The release of the internal energy can give rise to blast waves and high velocity vessel fragments.

- The release of the internal energy has to be considered in the determination of domino effects.

- In general, the release of internal energy does not need to be considered in the determination of effects outside the plant area.

4.10 Meteorological data

Meteorological data for the dispersion calculation can be expressed either in terms of the Monin-Obukhov length L, or the Pasquill classes. The two types of classification can be related to each other [CPR14E]. The use of the classification based on the Monin-Obukhov length L is recommended, if appropriate statistical data are available. However, the classification used should be consistent with the dispersion model and its dispersion coefficients.

In a QRA, at least six representative weather classes have to be used, covering the stability conditions stable, neutral and unstable, and low and high wind speeds. In case a classification in terms of Pasquill classes is used, at least the following six weather classes have to be covered:

Stability class	Wind speed (1)
B	medium
D	low
D	medium
D	high
E	medium
F	low

(1) Low wind speed corresponds with 1 - 2 m s^{-1}
Medium wind speed corresponds to 3 - 5 m s^{-1}
High wind speed corresponds to 8 - 9 m s^{-1}

The number of wind directions should be at least eight. The statistics of the meteorological situation should be deduced from a nearby, representative meteorological station. Some information on the grouping of meteorological data in weather classes and the statistics of a number of meteorological stations is included in Appendix 4.B.

The mixing height is normally not an important parameter in the calculation of lethal effects. Values for the mixing height are given in the ‘Yellow Book’ [CPR14E].

Default values for a number of meteorological parameters are given in Table 4.9. The values are intended as yearly averaged values. If necessary, discrete values in time should be used to distinguish between differences in day and night and between different periods in the year.

Table 4.9 Default values for a number of meteorological parameters

Parameter	Default value
ambient air temperature	282 K
soil/bund temperature	282 K
water temperature	282 K
ambient pressure	101510 N/m^2
humidity	83 %
solar radiation flux	0.12 kW/m^2

The wind speed, temperature and pressure varies with the height above the surface [CPR14E]. The vertical variation of the wind speed should be addressed according to the calculation in the ‘Yellow Book’. The minimum wind velocity is the wind velocity at a height of one metre.

Appendix 4.A Model to calculate the probability of delayed ignition

The probability of delayed ignition caused by an ignition source can be modelled as:

$$P(t) = P_{present} \cdot (1 - e^{-\omega t}), \tag{4.A.1}$$

where:

- $P(t)$ the probability of an ignition in the time interval 0 to t (-)
- $P_{present}$ the probability that the source is present when the cloud passes (-)
- ω the ignition effectiveness (s^{-1})
- t time (s).

The ignition effectiveness, ω, can be calculated given the probability of ignition for a certain time interval. Table 4.A.1 gives the probability of ignition for a time interval of one minute for a number of sources. It should be noted, however, that the numbers are not well established and should be used as a guideline.

Table 4.A.1 Probability of ignition for a time interval of one minute for a number of sources

Source	Probability of ignition in one minute
Point Source	
motor vehicle	0.4
flare	1.0
outdoor furnace	0.9
indoor furnace	0.45
outdoor boiler	0.45
indoor boiler	0.23
ship	0.5
ship transporting flammable materials	0.3
fishing vessel	0.2
pleasure craft	0.1
diesel train	0.4
electric train	0.8
Line source	
transmission line	0.2 per 100 m
road	Note 1
railway	Note 1
Area source	
chemical plant	0.9 per site
oil refinery	0.9 per site
heavy industry	0.7 per site
light industrial warehousing	as for population
Population source	
residential	0.01 per person
employment force	0.01 per person

Notes:

1. The ignition probability for a road or railway near the establishment or transport route under consideration is determined by the average traffic density. The average traffic density, d, is calculated as:

$$d = N\,E\,/\,v \qquad (4.A.2)$$

where:
N number of vehicles per hour (h^{-1})
E length of a road or railway section (km)
v average velocity of vehicle ($km\ h^{-1}$).

If $d \leq 1$, the value of d is the probability that the source is present when the cloud passes; the probability of an ignition in the time interval 0 to t, P(t), equals:

$$P(t) = d \cdot (1 - e^{-\omega t}), \qquad (4.A.3)$$

where:
ω the ignition effectiveness of a single vehicle (s^{-1})

If $d \geq 1$, d is the average number of sources present when the cloud passes; the probability of an ignition in the time interval 0 to t, P(t), equals:

$$P(t) = (1 - e^{-d\omega t}), \qquad (4.A.4)$$

where:
ω the ignition effectiveness of a single vehicle (s^{-1})

2. The probability of an ignition for a grid cell in a residential area in the time interval 0 to t, P(t), is given by:

$$P(t) = (1 - e^{-n\omega t}), \qquad (4.A.5)$$

where:
ω the ignition effectiveness of a single person (s^{-1})
n the average number of people present in the grid cell

3. Where the model uses a time-independent probability of ignition, the probability of ignition is equal to the probability of ignition in one minute.

Appendix 4.B Meteorological data

Information on meteorological data is often available in terms of wind direction, wind speed and stability classes. The information is usually expressed as fractional frequencies or numbers of observation. To limit the calculation time for the QRA, it is useful to group the data in a limited number of representative weather classes defined by wind speed and stability class.

It is recommended to use a classification of stability based on the Monin-Obukhov length L if appropriate statistical data of a weather station nearby are available [NNM98, CPR14E]. However, these long-term statistical data may not yet be readily available, in which case Pasquill stability classes may still be used. In this appendix an overview is given of the statistical data in terms of Pasquill stability classes, based on routine meteorological observations as wind speed, cloud cover and time of day.

In a QRA, at least six representative weather classes have to be used, covering the stability conditions of stable, neutral and unstable, and low and high wind speeds. In terms of Pasquill classes, at least the following six weather classes have to be covered (see Table 4.B.1).

Table 4.B.1 The six representative weather classes

Stability class	Wind speed (1)
B	Medium
D	Low
D	Medium
D	High
E	Medium
F	low

(1) Low wind speed corresponds with 1 - 2 m s^{-1}
Medium wind speed corresponds to 3 - 5 m s^{-1}
High wind speed corresponds to 8 - 9 m s^{-1}

To group the observations in the six weather classes, the following rules apply:

1. Observations in the Pasquill stability classes A, A/B, B and B/C are allocated to stability class B. The wind speed of the weather class is equal to the average wind speed of the observations.

2. Observations in the Pasquill stability classes C, C/D and D, are allocated to stability class D. Wind speeds below 2.5 m s^{-1} (5 knots), between 2.5 m s^{-1} and 6 m s^{-1} (12 knots) and above 6 m s^{-1} are allocated to the wind speed categories low, medium and high, respectively. The wind speed in each weather class is equal to the average wind speed of the observations in the weather class.

3. Observations in the Pasquill stability classes E and F are allocated on the basis of the wind speed. Wind speeds below 2.5 m s^{-1} and above 2.5 m s^{-1} are allocated to weather classes F and E, respectively. The wind speed in each weather class is equal to the average wind speed of the observations in the weather class.

The allocation is shown in Figure 4.B.1.

Figure 4.B.1 Allocation of observations into six weather classes.

<table>
<tr><th>Wind speed</th><th>A</th><th>B</th><th>B/C</th><th>C</th><th>C/D</th><th>D</th><th>E</th><th>F</th></tr>
<tr><td>< 2.5 m s⁻¹</td><td colspan="3" rowspan="3">B medium</td><td colspan="3">D low</td><td colspan="2">F low</td></tr>
<tr><td>2.5 - 6 m s⁻¹</td><td colspan="3">D medium</td><td colspan="2" rowspan="2">E medium</td></tr>
<tr><td>> 6 m s⁻¹</td><td colspan="3">D high</td></tr>
</table>

Data available can be separate for night-time and daytime, in which case, the period of the day attributed to daytime should have the daytime and night-time statistics added correctly. One should note that the population data are also divided in daytime and night-time. Care should be taken to combine the population and weather data correctly.

Frequency distributions of a number of meteorological stations are listed in the following tables, the data being compiled from [KNMI72]. The distributions with eight wind directions are derived from the distributions with twelve wind directions using the conversions in Table 4.B.2.

The 'day' period (i.e. day-time) refers to different time periods in different times of the year. For the month of June, daytime corresponds to the hours of 6.00 - 21.00 MET and night-time to the hours of 22.00 - 5.00 MET, whereas in December, daytime corresponds to the hours 10.00 - 16.00 MET and night-time to the hours of 17.00 - 9.00 MET. On average, daytime corresponds to the time period 8:00 - 18:30 MET (fraction of 0.44) and night-time corresponds to 18:30 - 8:00 MET (fraction 0.56).

Direction 346-015 corresponds with wind coming from North.

Table 4.B.2 Conversion from the distribution with twelve wind directions to the distribution with eight wind directions

Stability class	Wind direction
B 3.0 m s^{-1} → B 4.0 m s^{-1}	fraction (N-NO) = 0.5 × fraction (346-015) + fraction (016-
D 1.5 m s^{-1} → D 1.5 m s^{-1}	045)
D 5.0 m s^{-1} → D 4.0 m s^{-1}	fraction (NO-O) = fraction (046-075) + 0.5 × fraction (076-
D 9.0 m s^{-1} → D 8.0 m s^{-1}	105)
E 5.0 m s^{-1} → F 4.0 m s^{-1}	……
F 1.5 m s^{-1} → F 1.5 m s^{-1}	…

Beek							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	2.01	0.99	2.01	0.72	0.00	0.00	5.73
016-045	2.39	0.69	1.96	1.13	0.00	0.00	6.17
046-075	3.33	0.80	2.21	1.91	0.00	0.00	8.26
076-105	2.25	0.64	1.66	2.21	0.00	0.00	6.76
106-135	0.97	0.49	0.64	0.28	0.00	0.00	2.38
136-165	0.96	0.54	0.92	0.56	0.00	0.00	2.97
166-195	1.91	0.88	2.67	2.78	0.00	0.00	8.24
196-225	3.03	1.53	5.88	7.10	0.00	0.00	17.54
226-255	3.49	2.27	7.89	6.31	0.00	0.00	19.96
256-285	2.29	1.82	4.54	2.45	0.00	0.00	11.11
286-315	1.20	1.19	2.44	1.25	0.00	0.00	6.07
316-345	1.28	0.99	1.80	0.76	0.00	0.00	4.84
Total	25.11	12.83	34.61	27.46	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	0.88	1.33	0.39	0.60	1.04	4.24
016-045	0.00	0.79	1.84	0.77	1.06	1.21	5.67
046-075	0.00	0.94	2.00	1.15	1.79	1.83	7.69
076-105	0.00	0.77	1.87	1.22	1.76	1.61	7.23
106-135	0.00	0.72	1.13	0.26	0.96	1.49	4.56
136-165	0.00	0.93	1.50	0.64	1.11	1.89	6.07
166-195	0.00	1.41	5.01	3.64	2.51	2.32	14.88
196-225	0.00	2.14	7.38	6.99	2.56	2.11	21.18
226-255	0.00	2.49	5.46	3.80	1.08	1.61	14.44
256-285	0.00	1.78	2.66	1.06	0.45	1.15	7.10
286-315	0.00	1.13	1.36	0.40	0.25	0.77	3.91
316-345	0.00	0.84	0.98	0.19	0.25	0.80	3.05
Total	0.00	14.80	32.51	20.48	14.38	17.83	100.00

Beek									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	3.4	4.5	2.1	1.9	4.0	4.6	2.3	2.3	25.1
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.2	1.1	0.8	1.0	2.0	3.2	2.1	1.5	12.8
D 4.0 m/s	3.0	3.0	1.5	2.3	7.2	10.2	4.7	2.8	34.6
D 8.0 m/s	1.5	3.0	1.4	1.9	8.5	7.5	2.5	1.1	27.5
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.0	11.6	5.8	7.1	21.7	25.5	11.6	7.7	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.2	1.3	1.1	1.6	2.8	3.4	2.0	1.3	14.8
D 4.0 m/s	2.5	2.9	2.1	4.0	9.9	6.8	2.7	1.6	32.5
D 8.0 m/s	1.0	1.8	0.9	2.5	8.8	4.3	0.9	0.4	20.5
F 1.5 m/s	1.7	2.6	2.3	3.1	3.3	2.2	1.3	1.3	17.8
F 4.0 m/s	1.4	2.7	1.8	2.4	3.8	1.3	0.5	0.5	14.4
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	7.8	11.3	8.2	13.5	28.6	18.0	7.5	5.2	100.0

Deelen							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.17	1.18	1.51	0.84	0.00	0.00	4.70
016-045	2.09	1.49	1.39	0.65	0.00	0.00	5.62
046-075	3.21	1.57	2.14	1.64	0.00	0.00	8.55
076-105	2.89	1.17	1.92	1.63	0.00	0.00	7.61
106-135	2.07	0.91	1.41	0.77	0.00	0.00	5.16
136-165	1.88	1.27	2.07	1.23	0.00	0.00	6.44
166-195	1.36	1.53	2.67	2.07	0.00	0.00	7.63
196-225	1.60	1.89	4.64	4.48	0.00	0.00	12.60
226-255	1.66	1.76	4.87	6.39	0.00	0.00	14.67
256-285	1.09	1.39	3.63	5.01	0.00	0.00	11.12
286-315	1.20	1.26	3.07	3.42	0.00	0.00	8.95
316-345	1.32	1.20	2.13	2.30	0.00	0.00	6.95
Total	21.54	16.61	31.44	30.43	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	1.37	0.71	0.19	0.30	2.35	4.91
016-045	0.00	1.50	1.10	0.47	0.64	2.76	6.47
046-075	0.00	1.84	2.68	1.45	2.18	3.35	11.50
076-105	0.00	1.38	2.27	1.01	1.73	3.49	9.88
106-135	0.00	1.66	1.51	0.41	1.23	4.20	9.01
136-165	0.00	1.54	1.88	1.04	0.62	2.39	7.47
166-195	0.00	1.72	2.28	1.75	0.45	1.53	7.73
196-225	0.00	2.12	3.76	3.49	0.87	2.13	12.36
226-255	0.00	1.97	3.74	4.26	0.80	1.69	12.45
256-285	0.00	1.60	2.55	2.26	0.61	1.38	8.40
286-315	0.00	1.37	1.32	0.99	0.29	1.20	5.16
316-345	0.00	1.33	0.92	0.42	0.21	1.78	4.66
Total	0.00	19.39	24.71	17.74	9.92	28.25	100.00

Deelen									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	2.7	4.7	3.5	2.6	2.3	2.2	1.7	1.9	21.5
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	2.1	2.2	1.5	2.0	2.7	2.5	2.0	1.8	16.6
D 4.0 m/s	2.1	3.1	2.4	3.4	6.0	6.7	4.9	2.9	31.4
D 8.0 m/s	1.1	2.5	1.6	2.3	5.5	8.9	5.9	2.7	30.4
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	8.0	12.4	9.0	10.3	16.4	20.2	14.5	9.3	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	2.2	2.5	2.3	2.4	3.0	2.8	2.2	2.0	19.4
D 4.0 m/s	1.5	3.8	2.6	3.0	4.9	5.0	2.6	1.3	24.7
D 8.0 m/s	0.6	2.0	0.9	1.9	4.4	5.4	2.1	0.5	17.7
F 1.5 m/s	3.9	5.1	5.9	3.2	2.9	2.4	1.9	3.0	28.2
F 4.0 m/s	0.8	3.0	2.1	0.8	1.1	1.1	0.6	0.4	9.9
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	8.9	16.4	14.0	11.3	16.2	16.7	9.4	7.1	100.0

Den Helder							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.52	0.25	1.10	4.81	0.00	0.00	6.68
016-045	0.71	0.28	1.02	4.34	0.00	0.00	6.36
046-075	1.80	0.37	1.69	5.01	0.00	0.00	8.87
076-105	1.43	0.36	1.93	3.38	0.00	0.00	7.10
106-135	0.96	0.40	1.43	1.37	0.00	0.00	4.15
136-165	0.73	0.52	1.36	0.49	0.00	0.00	3.10
166-195	1.21	0.71	2.59	3.26	0.00	0.00	7.77
196-225	0.73	0.46	1.98	11.30	0.00	0.00	14.47
226-255	1.17	0.38	2.32	9.79	0.00	0.00	13.67
256-285	1.29	0.44	1.91	7.28	0.00	0.00	10.92
286-315	1.20	0.37	1.32	5.13	0.00	0.00	8.02
316-345	1.09	0.36	1.43	6.03	0.00	0.00	8.91
Total	12.83	4.90	20.08	62.20	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	0.36	2.01	4.04	0.81	0.47	7.70
016-045	0.00	0.34	1.56	2.85	0.63	0.49	5.86
046-075	0.00	0.20	0.84	3.78	0.30	0.27	5.38
076-105	0.00	0.41	2.36	4.80	1.07	0.49	9.14
106-135	0.00	0.58	2.06	1.67	1.06	0.78	6.15
136-165	0.00	0.95	2.02	0.61	1.04	1.13	5.75
166-195	0.00	1.31	4.66	4.06	2.22	1.39	13.63
196-225	0.00	0.53	2.04	9.04	0.71	0.77	13.08
226-255	0.00	0.30	1.76	7.28	0.46	0.38	10.17
256-285	0.00	0.32	1.56	7.09	0.44	0.31	9.71
286-315	0.00	0.20	0.98	4.89	0.30	0.24	6.61
316-345	0.00	0.24	1.06	4.98	0.28	0.25	6.82
Total	0.00	5.75	22.89	55.08	9.31	6.97	100.00

Den Helder								
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	1.0	2.5	1.7	1.3	1.3	1.8	1.8	1.4	12.8
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	0.4	0.5	0.6	0.9	0.8	0.6	0.6	0.5	4.9
D 4.0 m/s	1.6	2.7	2.4	2.7	3.3	3.3	2.3	2.0	20.1
D 8.0 m/s	6.7	6.7	3.1	2.1	2.9	13.4	8.8	8.4	52.2
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.7	12.4	7.7	7.0	8.4	19.1	13.5	12.2	90.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	0.5	0.4	0.8	1.6	1.2	0.5	0.4	0.4	5.7
D 4.0 m/s	2.6	2.0	3.2	4.3	4.4	2.5	1.8	2.1	22.9
D 8.0 m/s	4.9	6.2	4.1	2.6	11.1	10.8	8.4	7.0	55.1
F 1.5 m/s	0.7	0.5	1.0	1.8	1.5	0.5	0.4	0.5	7.0
F 4.0 m/s	1.0	0.8	1.6	2.2	1.8	0.7	0.5	0.7	9.3
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.7	10.0	10.7	12.6	19.9	15.0	11.5	10.7	100.0

Eelde							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.80	0.89	1.80	0.96	0.00	0.00	5.44
016-045	2.38	1.05	1.71	1.11	0.00	0.00	6.25
046-075	2.56	0.97	2.03	1.93	0.00	0.00	7.49
076-105	2.63	1.05	2.09	2.06	0.00	0.00	7.83
106-135	2.15	0.91	1.68	1.46	0.00	0.00	6.20
136-165	1.23	0.83	1.40	0.82	0.00	0.00	4.28
166-195	1.52	1.06	2.54	2.22	0.00	0.00	7.35
196-225	1.67	1.17	3.88	5.47	0.00	0.00	12.18
226-255	1.59	1.10	3.92	7.87	0.00	0.00	14.48
256-285	1.90	1.12	3.57	6.11	0.00	0.00	12.69
286-315	1.52	1.03	2.88	3.41	0.00	0.00	8.84
316-345	1.50	0.91	2.34	2.22	0.00	0.00	6.98
Total	22.43	12.09	29.85	35.63	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	0.91	0.74	0.29	0.33	1.35	3.62
016-045	0.00	1.19	0.99	0.32	0.66	2.25	5.41
046-075	0.00	1.15	2.00	1.43	1.34	2.84	8.76
076-105	0.00	1.22	2.22	1.51	1.54	2.65	9.15
106-135	0.00	1.41	1.77	0.98	0.90	2.22	7.27
136-165	0.00	1.24	1.45	0.74	0.54	1.67	5.63
166-195	0.00	1.49	2.68	2.04	0.94	2.01	9.16
196-225	0.00	1.76	4.59	4.52	1.64	2.55	15.07
226-255	0.00	1.52	3.96	5.15	1.57	2.34	14.54
256-285	0.00	1.71	2.80	2.68	1.12	2.56	10.87
286-315	0.00	1.40	1.53	1.19	0.42	1.84	6.38
316-345	0.00	0.90	1.14	0.64	0.28	1.20	4.15
Total	0.00	15.90	25.87	21.49	11.27	25.47	100.00

Eelde									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	3.3	3.9	3.5	2.0	2.4	2.5	2.5	2.4	22.4
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.5	1.5	1.4	1.4	1.7	1.7	1.6	1.4	12.1
D 4.0 m/s	2.6	3.1	2.7	2.7	5.1	5.7	4.7	3.2	29.8
D 8.0 m/s	1.6	3.0	2.5	1.9	6.6	10.9	6.5	2.7	35.6
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.0	11.4	10.1	7.9	15.8	20.8	15.2	9.7	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.6	1.8	2.0	2.0	2.5	2.4	2.3	1.4	15.9
D 4.0 m/s	1.4	3.1	2.9	2.8	5.9	5.4	2.9	1.5	25.9
D 8.0 m/s	0.5	2.2	1.7	1.8	5.5	6.5	2.5	0.8	21.5
F 1.5 m/s	2.9	4.2	3.5	2.7	3.6	3.6	3.1	1.9	25.5
F 4.0 m/s	0.8	2.1	1.7	1.0	2.1	2.1	1.0	0.4	11.3
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	7.2	13.3	11.8	10.2	19.6	20.0	11.8	6.0	100.0

Eindhoven							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.76	1.03	1.88	1.39	0.00	0.00	6.06
016-045	2.28	1.28	1.93	1.04	0.00	0.00	6.53
046-075	2.91	0.92	2.08	1.77	0.00	0.00	7.69
076-105	2.41	0.81	1.57	1.55	0.00	0.00	6.34
106-135	1.90	0.81	1.57	1.13	0.00	0.00	5.41
136-165	1.56	1.07	1.36	0.57	0.00	0.00	4.56
166-195	1.43	1.20	2.36	2.07	0.00	0.00	7.06
196-225	1.58	1.41	3.82	6.28	0.00	0.00	13.08
226-255	1.73	1.50	4.86	9.23	0.00	0.00	17.32
256-285	1.24	1.30	3.51	5.76	0.00	0.00	11.81
286-315	1.12	0.86	2.35	3.23	0.00	0.00	7.56
316-345	1.23	0.94	2.10	2.31	0.00	0.00	6.58
Total	21.15	13.14	29.39	36.32	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	0.83	1.00	0.42	0.60	1.84	4.69
016-045	0.00	1.40	1.44	0.60	0.95	2.73	7.11
046-075	0.00	1.14	2.00	1.03	1.53	2.90	8.61
076-105	0.00	0.80	1.47	1.04	1.17	1.83	6.31
106-135	0.00	1.27	1.60	0.80	1.00	2.38	7.05
136-165	0.00	1.54	1.69	0.56	0.81	2.46	7.05
166-195	0.00	1.80	2.56	1.75	0.88	2.47	9.45
196-225	0.00	1.89	4.05	5.10	1.33	2.41	14.77
226-255	0.00	1.76	4.41	6.31	1.22	1.78	15.49
256-285	0.00	1.48	2.54	2.82	0.82	1.68	9.33
286-315	0.00	1.08	1.39	1.04	0.49	1.45	5.45
316-345	0.00	0.87	1.15	0.56	0.39	1.71	4.69
Total	0.00	15.84	25.29	22.04	11.20	25.63	100.00

Eindhoven									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	3.2	4.1	3.1	2.3	2.3	2.4	1.7	2.1	21.1
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.8	1.3	1.2	1.7	2.0	2.2	1.5	1.5	13.1
D 4.0 m/s	2.9	2.9	2.4	2.5	5.0	6.6	4.1	3.0	29.4
D 8.0 m/s	1.7	2.5	1.9	1.6	7.3	12.1	6.1	3.0	36.3
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.6	10.9	8.6	8.1	16.6	23.2	13.5	9.6	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.8	1.5	1.7	2.4	2.8	2.5	1.8	1.3	15.8
D 4.0 m/s	1.9	2.7	2.3	3.0	5.3	5.7	2.7	1.6	25.3
D 8.0 m/s	0.8	1.6	1.3	1.4	6.0	7.7	2.5	0.8	22.0
F 1.5 m/s	3.6	3.8	3.3	3.7	3.6	2.6	2.3	2.6	25.6
F 4.0 m/s	1.3	2.1	1.6	1.2	1.8	1.6	0.9	0.7	11.2
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.5	11.8	10.2	11.8	19.5	20.2	10.1	7.0	100.0

Gilze-Rijen							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	2.06	1.24	2.11	0.98	0.00	0.00	6.39
016-045	2.90	1.35	2.37	1.51	0.00	0.00	8.14
046-075	2.67	0.94	2.07	2.30	0.00	0.00	7.98
076-105	1.53	0.66	1.33	1.72	0.00	0.00	5.24
106-135	1.46	0.68	1.31	1.06	0.00	0.00	4.51
136-165	1.20	0.81	1.44	0.70	0.00	0.00	4.14
166-195	1.18	0.97	2.50	2.51	0.00	0.00	7.16
196-225	1.74	1.45	4.70	5.71	0.00	0.00	13.60
226-255	2.01	1.67	5.14	7.20	0.00	0.00	16.01
256-285	1.99	1.63	4.02	5.10	0.00	0.00	12.74
286-315	1.55	1.41	3.14	2.24	0.00	0.00	8.34
316-345	1.30	1.05	2.22	1.17	0.00	0.00	5.74
Total	21.59	13.87	32.34	32.20	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	1.36	1.06	0.30	0.96	3.02	6.70
016-045	0.00	1.43	1.62	0.65	1.29	3.47	8.45
046-075	0.00	1.06	1.81	1.32	1.24	2.37	7.79
076-105	0.00	0.72	1.00	0.85	0.62	1.20	4.38
106-135	0.00	0.91	1.30	0.62	0.65	1.47	4.94
136-165	0.00	1.08	1.43	0.66	0.64	1.98	5.79
166-195	0.00	1.43	2.93	2.20	1.06	1.92	9.54
196-225	0.00	2.21	4.58	4.47	1.66	2.87	15.79
226-255	0.00	2.40	4.44	4.96	1.69	3.33	16.81
256-285	0.00	2.02	2.24	1.95	0.81	2.98	9.99
286-315	0.00	1.44	1.37	0.60	0.41	1.88	5.70
316-345	0.00	1.05	0.80	0.25	0.35	1.67	4.13
Total	0.00	17.10	24.56	18.81	11.37	28.16	100.00

Gilze-rijen									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	3.9	3.4	2.2	1.8	2.3	3.0	2.5	2.3	21.6
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	2.0	1.3	1.0	1.3	1.9	2.5	2.2	1.7	13.9
D 4.0 m/s	3.4	2.7	2.0	2.7	5.9	7.2	5.2	3.3	32.3
D 8.0 m/s	2.0	3.2	1.9	2.0	7.0	9.7	4.8	1.7	32.2
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	11.3	10.6	7.1	7.7	17.2	22.4	14.7	8.9	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	2.1	1.4	1.3	1.8	2.9	3.4	2.4	1.7	17.1
D 4.0 m/s	2.1	2.3	1.8	2.9	6.0	5.6	2.5	1.3	24.6
D 8.0 m/s	0.8	1.7	1.0	1.8	5.6	5.9	1.6	0.4	18.8
F 1.5 m/s	5.0	3.0	2.1	2.9	3.8	4.8	3.4	3.2	28.2
F 4.0 m/s	1.8	1.5	1.0	1.2	2.2	2.1	0.8	0.8	11.4
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	11.8	10.0	7.1	10.6	20.6	21.8	10.7	7.5	100.0

Hoek van Holland							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	2.36	0.67	2.75	5.01	0.00	0.00	10.79
016-045	1.18	0.49	1.77	2.33	0.00	0.00	5.77
046-075	1.25	0.70	1.71	1.61	0.00	0.00	5.26
076-105	2.86	0.99	2.24	1.77	0.00	0.00	7.85
106-135	1.35	0.60	1.38	1.14	0.00	0.00	4.47
136-165	1.60	0.79	1.81	1.56	0.00	0.00	5.77
166-195	1.00	0.70	2.46	3.77	0.00	0.00	7.92
196-225	0.62	0.47	1.97	6.31	0.00	0.00	9.37
226-255	1.25	0.48	2.42	11.38	0.00	0.00	15.53
256-285	2.01	0.65	2.51	6.12	0.00	0.00	11.29
286-315	1.63	0.69	1.82	3.91	0.00	0.00	8.05
316-345	1.69	0.64	1.85	3.77	0.00	0.00	7.94
Total	18.77	7.87	24.69	48.66	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	0.44	1.48	2.73	0.43	0.49	5.57
016-045	0.00	0.84	1.82	1.58	1.23	1.09	6.57
046-075	0.00	1.32	2.37	1.67	1.82	2.25	9.42
076-105	0.00	1.67	2.92	1.31	2.92	2.77	11.58
106-135	0.00	0.77	1.62	0.90	0.95	1.34	5.56
136-165	0.00	0.87	2.30	1.70	0.85	1.23	6.96
166-195	0.00	1.06	3.37	4.14	1.23	1.26	11.07
196-225	0.00	0.51	2.31	6.55	0.63	0.57	10.58
226-255	0.00	0.39	1.94	8.50	0.54	0.46	11.82
256-285	0.00	0.46	1.80	5.41	0.35	0.38	8.39
286-315	0.00	0.36	1.33	4.41	0.30	0.43	6.82
316-345	0.00	0.37	1.33	3.28	0.32	0.39	5.68
Total	0.00	9.07	24.56	42.18	11.54	12.65	100.00

Hoek van Holland									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	2.4	2.7	2.8	2.1	1.1	2.2	2.6	2.9	18.8
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	0.8	1.2	1.1	1.1	0.8	0.8	1.0	1.0	7.9
D 4.0 m/s	3.1	2.8	2.5	3.0	3.2	3.7	3.1	3.2	24.7
D 8.0 m/s	4.8	2.5	2.0	3.4	8.2	14.4	7.0	6.3	48.7
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	11.2	9.2	8.4	9.7	13.3	11.2	13.7	13.3	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.1	2.2	1.6	1.4	1.0	0.6	0.6	0.6	9.1
D 4.0 m/s	2.6	3.8	3.1	4.0	4.0	2.8	2.2	2.1	24.6
D 8.0 m/s	2.9	2.3	1.6	3.8	8.6	11.2	7.1	4.6	42.2
F 1.5 m/s	1.3	3.6	2.7	1.9	1.2	0.6	0.6	0.6	12.6
F 4.0 m/s	1.4	3.3	2.4	1.5	1.2	0.7	0.5	0.5	11.5
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.4	15.2	11.4	12.5	16.1	16.0	11.0	8.5	100.0

IJmuiden							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.87	0.48	1.80	3.94	0.00	0.00	7.09
016-045	0.71	0.41	1.57	1.84	0.00	0.00	4.53
046-075	1.15	0.37	1.59	3.10	0.00	0.00	6.21
076-105	2.11	0.54	2.74	4.39	0.00	0.00	9.77
106-135	1.25	0.65	1.62	1.60	0.00	0.00	5.11
136-165	0.86	0.67	1.96	2.04	0.00	0.00	5.51
166-195	0.58	0.58	1.99	2.99	0.00	0.00	6.13
196-225	0.91	0.52	2.31	8.06	0.00	0.00	11.80
226-255	1.65	0.57	2.65	9.95	0.00	0.00	14.82
256-285	1.50	0.55	2.08	7.11	0.00	0.00	11.24
286-315	1.24	0.51	1.83	5.29	0.00	0.00	8.86
316-345	1.41	0.49	2.16	4.85	0.00	0.00	8.91
Total	14.23	6.33	24.29	55.15	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	0.56	1.39	1.69	0.48	0.45	4.58
016-045	0.00	0.73	2.59	1.70	1.35	0.80	7.17
046-075	0.00	0.40	1.76	3.11	1.05	0.69	7.02
076-105	0.00	0.85	3.47	4.35	2.42	1.37	12.45
106-135	0.00	1.09	2.28	1.48	1.33	1.15	7.33
136-165	0.00	1.11	3.05	2.32	1.39	1.23	9.09
166-195	0.00	0.97	2.80	3.62	1.19	0.88	9.45
196-225	0.00	0.36	1.77	6.89	0.53	0.42	9.96
226-255	0.00	0.31	1.55	8.04	0.37	0.40	10.67
256-285	0.00	0.25	1.45	6.91	0.40	0.32	9.32
286-315	0.00	0.26	1.17	5.36	0.30	0.26	7.34
316-345	0.00	0.29	1.14	3.71	0.23	0.27	5.63
Total	0.00	7.18	24.40	49.17	11.03	8.23	100.00

IJmuiden									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	1.1	2.2	2.3	1.1	1.2	2.4	2.0	1.8	14.2
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	0.6	0.6	0.9	1.0	0.8	0.8	0.8	0.7	6.3
D 4.0 m/s	2.5	3.0	3.0	2.9	3.3	3.7	2.9	3.1	24.3
D 8.0 m/s	3.8	5.3	3.8	3.5	9.6	13.5	8.8	6.8	55.2
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	8.1	11.1	10.0	8.6	14.9	20.4	14.5	12.5	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.0	0.8	1.5	1.6	0.8	0.4	0.4	0.6	7.2
D 4.0 m/s	3.3	3.5	4.0	4.4	3.2	2.3	1.9	1.8	24.4
D 8.0 m/s	2.5	5.3	3.7	4.1	8.7	11.5	8.8	4.6	49.2
F 1.5 m/s	1.0	1.4	1.8	1.7	0.9	0.6	0.4	0.5	8.2
F 4.0 m/s	1.6	2.3	2.5	2.0	1.1	0.6	0.5	0.5	11.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.5	13.2	13.6	13.8	14.7	15.3	12.0	7.9	100.0

Leeuwarden							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.42	0.77	2.07	1.87	0.00	0.00	6.13
016-045	1.92	0.84	2.13	2.33	0.00	0.00	7.22
046-075	1.84	0.88	1.88	2.48	0.00	0.00	7.08
076-105	2.23	0.97	1.91	2.58	0.00	0.00	7.69
106-135	1.25	0.74	1.45	1.02	0.00	0.00	4.45
136-165	1.13	0.82	1.74	0.92	0.00	0.00	4.62
166-195	1.77	1.45	2.93	2.56	0.00	0.00	8.70
196-225	1.70	1.50	3.89	5.91	0.00	0.00	13.00
226-255	1.47	1.17	3.37	6.87	0.00	0.00	12.87
256-285	1.49	0.91	2.93	6.75	0.00	0.00	12.09
286-315	1.12	0.69	2.10	4.28	0.00	0.00	8.19
316-345	1.28	0.68	2.35	3.66	0.00	0.00	7.96
Total	18.63	11.42	28.75	41.21	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	0.85	1.17	0.76	0.47	1.23	4.48
016-045	0.00	1.02	1.28	0.72	0.71	1.63	5.36
046-075	0.00	1.15	1.74	1.43	1.27	2.33	7.92
076-105	0.00	1.17	2.19	2.08	1.77	2.48	9.68
106-135	0.00	0.87	1.73	1.05	0.99	1.38	6.03
136-165	0.00	1.08	2.20	1.07	0.82	1.21	6.37
166-195	0.00	1.85	3.52	2.40	1.73	2.74	12.23
196-225	0.00	2.00	4.05	4.84	1.72	3.10	15.71
226-255	0.00	1.40	2.82	3.78	1.03	2.09	11.11
256-285	0.00	1.10	2.10	3.26	0.84	1.55	8.85
286-315	0.00	0.87	1.61	2.40	0.70	1.03	6.60
316-345	0.00	0.90	1.46	1.79	0.44	1.06	5.65
Total	0.00	14.25	25.87	25.57	12.50	21.82	100.00

Leeuwarden									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	2.6	3.0	2.4	2.0	2.6	2.2	1.9	2.0	18.6
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.2	1.4	1.2	1.5	2.2	1.6	1.2	1.1	11.4
D 4.0 m/s	3.2	2.8	2.4	3.2	5.3	4.8	3.6	3.4	28.7
D 8.0 m/s	3.3	3.8	2.3	2.2	7.2	10.2	7.7	4.6	41.2
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	10.3	10.9	8.3	9.0	17.4	18.9	14.2	11.0	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.4	1.7	1.5	2.0	2.9	1.9	1.4	1.3	14.3
D 4.0 m/s	1.9	2.8	2.8	4.0	5.8	3.9	2.7	2.1	25.9
D 8.0 m/s	1.1	2.5	2.1	2.3	6.0	5.4	4.0	2.2	25.6
F 1.5 m/s	2.2	3.6	2.6	2.6	4.5	2.9	1.8	1.7	21.8
F 4.0 m/s	0.9	2.2	1.9	1.7	2.6	1.5	1.1	0.7	12.5
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	7.6	12.8	10.9	12.5	21.8	15.5	11.0	7.9	100.0

Rotterdam							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	2.17	0.84	2.26	1.88	0.00	0.00	7.16
016-045	1.97	0.84	1.62	1.42	0.00	0.00	5.85
046-075	2.86	0.85	2.13	2.23	0.00	0.00	8.07
076-105	2.91	0.84	2.02	1.89	0.00	0.00	7.66
106-135	1.58	0.52	1.40	0.93	0.00	0.00	4.43
136-165	1.31	0.88	1.61	0.81	0.00	0.00	4.60
166-195	1.66	1.19	3.26	2.44	0.00	0.00	8.54
196-225	1.64	1.08	3.76	4.86	0.00	0.00	11.34
226-255	2.04	1.31	3.86	7.11	0.00	0.00	14.33
256-285	2.75	1.36	4.09	4.38	0.00	0.00	12.57
286-315	2.40	0.87	2.74	2.88	0.00	0.00	8.90
316-345	1.22	0.61	2.01	2.72	0.00	0.00	6.57
Total	24.50	11.19	30.76	33.55	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	1.19	1.13	0.46	0.54	2.44	5.76
016-045	0.00	1.20	1.30	0.61	0.77	2.66	6.53
046-075	0.00	1.17	2.26	1.67	1.52	2.96	9.58
076-105	0.00	1.22	1.83	1.01	1.20	2.26	7.51
106-135	0.00	0.79	1.30	0.53	0.71	1.42	4.75
136-165	0.00	1.19	2.08	0.80	0.74	1.50	6.31
166-195	0.00	1.55	3.75	2.37	1.15	2.10	10.91
196-225	0.00	1.49	3.62	4.79	1.26	2.50	13.65
226-255	0.00	1.93	3.81	4.76	1.15	3.30	14.96
256-285	0.00	1.66	2.26	1.96	0.88	2.24	8.99
286-315	0.00	0.94	1.51	1.78	0.53	1.45	6.20
316-345	0.00	0.86	1.23	1.13	0.41	1.22	4.86
Total	0.00	15.19	26.06	21.87	10.85	26.04	100.00

Rotterdam									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	3.1	4.3	3.0	2.1	2.5	3.4	3.8	2.3	24.5
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.3	1.3	0.9	1.5	1.7	2.0	1.6	1.0	11.2
D 4.0 m/s	2.8	3.1	2.4	3.2	5.4	5.9	4.8	3.1	30.8
D 8.0 m/s	2.4	3.2	1.9	2.0	6.1	9.3	5.1	3.7	33.6
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.4	11.9	8.3	8.9	15.6	20.6	15.2	10.2	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.8	1.8	1.4	2.0	2.3	2.8	1.8	1.5	15.2
D 4.0 m/s	1.9	3.2	2.2	4.0	5.5	4.9	2.6	1.8	26.1
D 8.0 m/s	0.8	2.2	1.0	2.0	6.0	5.7	2.8	1.4	21.9
F 1.5 m/s	3.9	4.1	2.5	2.6	3.5	4.4	2.6	2.4	26.0
F 4.0 m/s	1.0	2.1	1.3	1.3	1.8	1.6	1.0	0.7	10.8
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.4	13.3	8.5	11.8	19.1	19.5	10.7	7.7	100.0

Schiphol							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.25	0.62	1.84	2.63	0.00	0.00	6.33
016-045	1.23	0.45	1.50	2.44	0.00	0.00	5.62
046-075	2.09	0.62	2.36	4.12	0.00	0.00	9.18
076-105	2.01	0.69	1.86	1.88	0.00	0.00	6.45
106-135	1.32	0.54	1.35	0.95	0.00	0.00	4.15
136-165	1.30	0.76	2.00	1.56	0.00	0.00	5.62
166-195	1.49	0.94	2.85	3.04	0.00	0.00	8.33
196-225	1.19	0.83	3.24	6.26	0.00	0.00	11.51
226-255	1.23	0.78	2.62	9.44	0.00	0.00	14.07
256-285	1.58	0.75	3.01	7.52	0.00	0.00	12.86
286-315	1.21	0.61	2.02	4.46	0.00	0.00	8.31
316-345	1.23	0.60	1.93	3.82	0.00	0.00	7.58
Total	17.12	8.17	26.59	48.12	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	0.83	1.60	1.03	0.83	1.87	6.15
016-045	0.00	0.55	1.24	1.33	0.69	1.04	4.84
046-075	0.00	0.75	2.15	3.11	1.21	1.27	8.49
076-105	0.00	0.90	2.42	2.20	1.63	1.53	8.68
106-135	0.00	0.86	1.60	0.67	0.83	1.36	5.32
136-165	0.00	1.14	2.74	1.81	1.27	1.61	8.57
166-195	0.00	1.51	3.76	2.99	1.31	2.10	11.66
196-225	0.00	1.19	4.14	5.99	1.38	1.36	14.06
226-255	0.00	1.24	2.66	5.28	1.01	1.75	11.94
256-285	0.00	0.96	1.77	3.60	0.67	1.26	8.26
286-315	0.00	0.73	1.35	2.36	0.49	1.03	5.96
316-345	0.00	0.86	1.65	1.48	0.62	1.46	6.06
Total	0.00	11.52	27.07	31.85	11.91	17.65	100.00

Schiphol									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	1.9	3.1	2.3	2.0	1.9	2.0	2.0	1.9	17.1
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	0.8	1.0	0.9	1.2	1.3	1.2	1.0	0.9	8.2
D 4.0 m/s	2.4	3.3	2.3	3.4	4.7	4.1	3.5	2.8	26.6
D 8.0 m/s	3.8	5.1	1.9	3.1	7.8	13.2	8.2	5.1	48.1
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	8.8	12.4	7.4	9.8	15.7	20.5	14.7	10.7	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.0	1.2	1.3	1.9	1.9	1.7	1.2	1.3	11.5
D 4.0 m/s	2.0	3.4	2.8	4.6	6.0	3.5	2.2	2.4	27.1
D 8.0 m/s	1.8	4.2	1.8	3.3	7.5	7.1	4.2	2.0	31.9
F 1.5 m/s	2.0	2.0	2.1	2.7	2.4	2.4	1.7	2.4	17.7
F 4.0 m/s	1.1	2.0	1.6	1.9	2.0	1.3	0.8	1.0	11.9
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	7.9	12.8	9.7	14.4	19.9	16.1	10.1	9.1	100.0

Soesterberg							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.99	1.49	2.59	1.53	0.00	0.00	7.60
016-045	3.75	1.74	2.86	1.44	0.00	0.00	9.79
046-075	2.16	1.18	1.67	1.02	0.00	0.00	6.03
076-105	2.33	1.11	1.61	1.20	0.00	0.00	6.25
106-135	1.62	0.98	1.35	0.48	0.00	0.00	4.43
136-165	1.33	1.34	1.76	0.57	0.00	0.00	5.01
166-195	1.51	2.03	3.01	1.19	0.00	0.00	7.74
196-225	1.65	2.45	5.37	3.53	0.00	0.00	13.00
226-255	1.39	1.59	4.70	5.15	0.00	0.00	12.83
256-285	1.51	1.58	3.82	4.84	0.00	0.00	11.76
286-315	1.64	1.25	3.99	2.73	0.00	0.00	9.62
316-345	1.04	1.13	2.16	1.64	0.00	0.00	5.96
Total	21.93	17.85	34.91	25.32	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	1.42	0.98	0.25	0.37	2.24	5.26
016-045	0.00	2.24	1.98	0.52	1.26	4.07	10.07
046-075	0.00	1.44	1.67	0.67	1.13	2.96	7.87
076-105	0.00	1.50	1.66	0.67	1.41	3.27	8.50
106-135	0.00	1.39	0.97	0.21	0.52	2.58	5.67
136-165	0.00	2.00	1.77	0.59	0.54	3.08	7.97
166-195	0.00	3.13	2.72	1.05	0.75	3.57	11.23
196-225	0.00	3.01	4.27	2.67	0.97	3.02	13.93
226-255	0.00	2.04	3.53	3.33	0.74	1.82	11.46
256-285	0.00	1.85	2.15	1.83	0.62	1.90	8.34
286-315	0.00	1.31	1.24	0.68	0.35	1.64	5.22
316-345	0.00	1.17	1.12	0.42	0.21	1.55	4.48
Total	0.00	22.49	24.07	12.88	8.88	31.69	100.00

Soesterberg									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	4.7	3.3	2.8	2.1	2.4	2.1	2.4	2.0	21.9
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	2.5	1.7	1.5	2.4	3.5	2.4	2.0	1.9	17.9
D 4.0 m/s	4.2	2.5	2.2	3.3	6.9	6.6	5.9	3.5	34.9
D 8.0 m/s	2.2	1.6	1.1	1.2	4.1	7.6	5.2	2.4	25.3
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	13.6	9.1	7.6	8.9	16.9	18.7	15.5	9.8	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	3.0	2.2	2.1	3.6	4.6	3.0	2.2	1.9	22.5
D 4.0 m/s	2.5	2.5	1.8	3.1	5.6	4.6	2.3	1.6	24.1
D 8.0 m/s	0.6	1.0	0.5	1.1	3.2	4.2	1.6	0.5	12.9
F 1.5 m/s	5.2	4.6	4.2	4.9	4.8	2.8	2.6	2.7	31.7
F 4.0 m/s	1.4	1.8	1.2	0.9	1.3	1.0	0.7	0.4	8.9
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	12.7	12.1	9.9	13.6	19.5	15.6	9.4	7.1	100.0

Twente							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.75	1.38	1.60	0.70	0.00	0.00	5.43
016-045	2.38	1.38	1.64	0.36	0.00	0.00	5.77
046-075	3.19	1.46	2.07	0.86	0.00	0.00	7.59
076-105	3.36	1.50	1.85	0.81	0.00	0.00	7.52
106-135	2.45	1.45	1.29	0.25	0.00	0.00	5.43
136-165	1.67	1.30	1.11	0.20	0.00	0.00	4.29
166-195	1.80	1.63	2.93	1.26	0.00	0.00	7.63
196-225	2.56	2.72	6.86	5.12	0.00	0.00	17.25
226-255	1.97	2.05	5.53	4.90	0.00	0.00	14.45
256-285	1.36	1.51	3.22	3.30	0.00	0.00	9.38
286-315	1.46	1.41	3.02	2.72	0.00	0.00	8.60
316-345	1.63	1.48	2.26	1.30	0.00	0.00	6.67
Total	25.59	19.25	33.38	21.78	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	1.07	0.69	0.18	0.27	1.46	3.66
016-045	0.00	1.48	1.16	0.14	0.61	2.66	6.04
046-075	0.00	1.81	2.00	0.54	1.67	3.39	9.41
076-105	0.00	1.73	1.86	0.61	1.94	3.24	9.39
106-135	0.00	1.71	1.18	0.16	1.25	2.88	7.18
136-165	0.00	1.60	1.15	0.22	0.60	2.49	6.06
166-195	0.00	2.26	3.21	1.13	1.47	3.03	11.10
196-225	0.00	3.19	5.98	4.32	1.73	3.35	18.57
226-255	0.00	2.21	4.09	3.40	0.99	1.99	12.68
256-285	0.00	1.46	2.06	1.57	0.52	1.51	7.12
286-315	0.00	1.38	1.30	0.84	0.35	1.37	5.24
316-345	0.00	1.10	0.88	0.28	0.17	1.12	3.56
Total	0.00	21.03	25.56	13.37	11.56	28.48	100.00

Twente									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	3.3	4.9	4.1	2.6	3.5	2.7	2.1	2.5	25.6
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	2.1	2.2	2.2	2.1	3.5	2.8	2.2	2.2	19.3
D 4.0 m/s	2.4	3.0	2.2	2.6	8.3	7.1	4.6	3.1	33.4
D 8.0 m/s	0.7	1.3	0.6	0.8	5.7	6.5	4.4	1.7	21.8
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	8.5	11.3	9.2	8.1	21.1	19.1	13.3	9.4	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	2.0	2.7	2.6	2.7	4.3	2.9	2.1	1.6	21.0
D 4.0 m/s	1.5	2.9	2.1	2.8	7.6	5.1	2.3	1.2	25.6
D 8.0 m/s	0.2	0.8	0.5	0.8	4.9	4.2	1.6	0.4	13.4
F 1.5 m/s	3.4	5.0	4.5	4.0	4.9	2.7	2.1	1.8	28.5
F 4.0 m/s	0.7	2.6	2.2	1.3	2.5	1.2	0.6	0.3	11.6
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	7.9	14.1	11.9	11.6	24.1	16.2	8.8	5.4	100.0

Valkenburg							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.93	0.65	2.40	4.32	0.00	0.00	9.30
016-045	1.26	0.75	1.59	1.61	0.00	0.00	5.20
046-075	1.93	0.81	2.01	2.87	0.00	0.00	7.62
076-105	1.89	0.72	1.79	1.99	0.00	0.00	6.39
106-135	1.16	0.51	1.26	1.39	0.00	0.00	4.32
136-165	1.44	0.78	1.76	1.57	0.00	0.00	5.56
166-195	1.32	0.96	2.12	2.43	0.00	0.00	6.84
196-225	0.76	0.85	2.74	5.24	0.00	0.00	9.59
226-255	1.00	0.79	3.01	9.86	0.00	0.00	14.66
256-285	2.13	0.99	3.94	6.77	0.00	0.00	13.83
286-315	1.71	0.76	2.38	3.96	0.00	0.00	8.81
316-345	1.58	0.65	2.11	3.55	0.00	0.00	7.89
Total	18.11	9.23	27.10	45.57	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	0.70	1.43	1.63	0.52	1.59	5.86
016-045	0.00	1.33	1.87	1.13	1.14	3.42	8.88
046-075	0.00	1.21	2.07	1.92	1.30	2.72	9.21
076-105	0.00	0.89	1.77	1.66	1.02	2.03	7.36
106-135	0.00	0.61	1.10	0.87	0.38	0.90	3.86
136-165	0.00	1.43	1.95	1.27	0.76	2.69	8.09
166-195	0.00	1.67	2.30	2.26	0.68	3.28	10.20
196-225	0.00	1.30	2.92	5.10	0.71	2.17	12.21
226-255	0.00	1.03	2.67	6.60	0.59	1.56	12.45
256-285	0.00	0.96	2.32	4.45	0.59	1.19	9.52
286-315	0.00	0.62	1.51	3.24	0.35	0.90	6.62
316-345	0.00	0.58	1.42	2.51	0.36	0.88	5.74
Total	0.00	12.34	23.33	32.63	8.38	23.32	100.00

Valkenburg								
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	2.2	2.9	2.1	2.1	1.4	2.1	2.8	2.5	18.1
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.1	1.2	0.9	1.3	1.3	1.3	1.3	1.0	9.2
D 4.0 m/s	2.8	2.9	2.2	2.8	3.8	5.0	4.4	3.3	27.1
D 8.0 m/s	3.8	3.9	2.4	2.8	6.5	13.2	7.3	5.7	45.6
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.9	10.8	7.5	9.0	13.0	21.6	15.7	12.5	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.7	1.7	1.1	2.3	2.1	1.5	1.1	0.9	12.3
D 4.0 m/s	2.6	3.0	2.0	3.1	4.1	3.8	2.7	2.1	23.3
D 8.0 m/s	1.9	2.7	1.7	2.4	6.2	8.8	5.5	3.3	32.6
F 1.5 m/s	4.2	3.7	1.9	4.3	3.8	2.2	1.5	1.7	23.3
F 4.0 m/s	1.4	1.8	0.9	1.1	1.1	0.9	0.6	0.6	8.4
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	11.8	12.9	7.5	13.2	17.3	17.2	11.4	8.7	100.0

Vlissingen							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	2.10	0.64	2.44	2.80	0.00	0.00	7.98
016-045	2.31	0.76	2.16	2.23	0.00	0.00	7.46
046-075	1.89	0.58	1.86	2.62	0.00	0.00	6.95
076-105	2.28	0.54	1.52	1.49	0.00	0.00	5.82
106-135	1.91	0.58	1.41	0.99	0.00	0.00	4.89
136-165	1.23	0.50	1.36	1.18	0.00	0.00	4.28
166-195	1.19	0.51	2.22	3.99	0.00	0.00	7.91
196-225	1.19	0.54	2.60	6.72	0.00	0.00	11.04
226-255	1.71	0.66	2.47	9.42	0.00	0.00	14.26
256-285	2.84	0.68	3.56	8.42	0.00	0.00	15.50
286-315	1.36	0.56	2.02	2.93	0.00	0.00	6.86
316-345	1.57	0.63	2.19	2.68	0.00	0.00	7.07
Total	21.56	7.18	25.80	45.46	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	0.86	1.57	0.86	0.89	1.62	5.79
016-045	0.00	1.19	2.24	1.47	2.02	2.45	9.37
046-075	0.00	1.02	2.61	2.05	2.12	1.77	9.56
076-105	0.00	0.62	1.55	1.49	0.98	1.22	5.86
106-135	0.00	0.48	1.34	1.09	0.60	0.82	4.34
136-165	0.00	0.54	2.04	1.68	0.73	0.78	5.76
166-195	0.00	0.66	3.10	5.00	0.83	0.81	10.39
196-225	0.00	0.68	3.92	8.58	1.15	1.04	15.38
226-255	0.00	0.58	2.80	7.94	0.92	0.83	13.07
256-285	0.00	0.61	1.72	3.90	0.51	0.81	7.54
286-315	0.00	0.72	1.69	2.63	0.70	1.16	6.89
316-345	0.00	0.94	1.65	1.11	0.69	1.67	6.06
Total	0.00	8.89	26.24	37.79	12.12	14.96	100.00

Vlissingen								
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	3.4	3.0	3.0	1.8	1.8	3.1	2.8	2.6	21.6
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.1	0.9	0.8	0.8	0.8	1.0	0.9	1.0	7.2
D 4.0 m/s	3.4	2.6	2.2	2.5	3.7	4.2	3.8	3.4	25.8
D 8.0 m/s	3.6	3.4	1.7	3.2	8.7	13.6	7.1	4.1	45.5
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	11.4	9.9	7.8	8.2	15.0	22.0	14.6	11.1	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.6	1.3	0.8	0.9	1.0	0.9	1.0	1.4	8.9
D 4.0 m/s	3.0	3.4	2.1	3.6	5.5	3.7	2.6	2.4	26.2
D 8.0 m/s	1.9	2.8	1.8	4.2	11.1	9.9	4.6	1.5	37.8
F 1.5 m/s	3.3	2.4	1.4	1.2	1.4	1.2	1.6	2.5	15.0
F 4.0 m/s	2.5	2.6	1.1	1.1	1.6	1.2	1.0	1.1	12.1
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	12.3	12.5	7.3	11.0	20.6	16.8	10.7	8.9	100.0

Volkel							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	2.11	1.38	1.91	0.94	0.00	0.00	6.34
016-045	2.23	1.22	1.65	1.06	0.00	0.00	6.15
046-075	3.02	1.08	1.95	2.03	0.00	0.00	8.08
076-105	2.50	0.92	1.49	1.41	0.00	0.00	6.31
106-135	1.76	0.76	1.18	0.79	0.00	0.00	4.49
136-165	1.50	1.04	1.45	0.95	0.00	0.00	4.94
166-195	1.60	1.61	2.56	1.91	0.00	0.00	7.68
196-225	2.12	2.18	4.35	4.79	0.00	0.00	13.43
226-255	2.45	2.37	5.90	6.24	0.00	0.00	16.95
256-285	2.00	2.11	4.24	3.97	0.00	0.00	12.33
286-315	1.59	1.48	2.70	1.94	0.00	0.00	7.71
316-345	1.32	1.21	1.94	1.10	0.00	0.00	5.58
Total	24.21	17.36	31.32	27.11	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	1.30	0.86	0.27	0.57	2.88	5.87
016-045	0.00	1.35	1.32	0.61	0.82	3.27	7.37
046-075	0.00	1.20	1.80	1.28	1.41	2.96	8.65
076-105	0.00	1.17	1.45	0.82	1.00	2.52	6.95
106-135	0.00	1.02	0.96	0.35	0.50	1.84	4.67
136-165	0.00	1.26	1.53	0.76	0.57	1.93	6.04
166-195	0.00	2.16	2.59	1.48	0.92	2.41	9.57
196-225	0.00	2.48	4.08	3.72	1.42	3.29	14.98
226-255	0.00	2.61	4.61	4.15	1.43	2.85	15.65
256-285	0.00	1.97	2.42	1.91	0.86	2.73	9.89
286-315	0.00	1.60	1.30	0.59	0.42	2.25	6.15
316-345	0.00	1.14	0.72	0.21	0.31	1.84	4.22
Total	0.00	19.24	23.64	16.13	10.22	30.77	100.00

Volkel									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	3.3	4.3	3.0	2.3	2.9	3.5	2.6	2.4	24.2
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.9	1.5	1.2	1.8	3.0	3.4	2.5	1.9	17.4
D 4.0 m/s	2.6	2.7	1.9	2.7	5.6	8.0	4.8	2.9	31.3
D 8.0 m/s	1.5	2.7	1.5	1.9	5.7	8.2	3.9	1.6	27.1
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.3	11.2	7.6	8.8	17.3	23.1	13.9	8.7	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	2.0	1.8	1.6	2.3	3.6	3.6	2.6	1.8	19.2
D 4.0 m/s	1.8	2.5	1.7	2.8	5.4	5.8	2.5	1.2	23.6
D 8.0 m/s	0.7	1.7	0.8	1.5	4.5	5.1	1.5	0.3	16.1
F 1.5 m/s	4.7	4.2	3.1	3.1	4.5	4.2	3.6	3.3	30.8
F 4.0 m/s	1.1	1.9	1.0	1.0	1.9	1.9	0.8	0.6	10.2
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	10.3	12.1	8.1	10.8	19.8	20.6	11.1	7.2	100.0

Woensdrecht							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.36	1.03	1.88	0.79	0.00	0.00	5.06
016-045	2.09	1.07	2.62	1.34	0.00	0.00	7.11
046-075	3.29	1.21	2.44	1.94	0.00	0.00	8.88
076-105	3.32	1.32	1.78	0.98	0.00	0.00	7.39
106-135	1.01	0.91	0.78	0.18	0.00	0.00	2.88
136-165	1.03	1.39	1.06	0.15	0.00	0.00	3.63
166-195	1.46	2.08	3.15	1.19	0.00	0.00	7.88
196-225	2.16	2.71	7.08	4.06	0.00	0.00	16.01
226-255	1.83	1.99	5.39	5.55	0.00	0.00	14.76
256-285	2.36	1.64	3.63	4.72	0.00	0.00	12.34
286-315	2.17	1.46	3.10	1.86	0.00	0.00	8.59
316-345	1.18	1.05	2.14	1.09	0.00	0.00	5.47
Total	23.24	17.87	35.05	23.83	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	1.16	0.72	0.14	0.28	1.95	4.25
016-045	0.00	1.51	1.55	0.64	1.11	2.93	7.74
046-075	0.00	1.67	2.41	1.38	1.88	4.10	11.44
076-105	0.00	1.81	1.20	0.47	0.95	4.04	8.46
106-135	0.00	1.70	0.58	0.09	0.19	2.30	4.87
136-165	0.00	1.88	0.81	0.08	0.23	2.44	5.43
166-195	0.00	3.02	3.00	1.18	0.76	3.25	11.21
196-225	0.00	3.62	5.80	3.21	1.78	4.00	18.40
226-255	0.00	2.36	4.46	3.18	1.05	2.44	13.48
256-285	0.00	1.14	1.55	1.68	0.40	1.21	5.97
286-315	0.00	1.17	1.20	0.72	0.38	1.38	4.85
316-345	0.00	1.22	0.84	0.25	0.18	1.42	3.91
Total	0.00	22.24	24.12	13.02	9.19	31.44	100.00

Woensdrecht									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	2.8	4.9	2.7	1.8	2.9	3.0	3.3	1.9	23.2
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.6	1.9	1.6	2.4	3.8	2.8	2.3	1.6	17.9
D 4.0 m/s	3.6	3.3	1.7	2.6	8.7	7.2	4.9	3.1	35.1
D 8.0 m/s	1.7	2.4	0.7	0.7	4.7	7.9	4.2	1.5	23.8
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.6	12.6	6.6	7.6	20.0	20.9	14.8	8.0	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	2.1	2.6	2.6	3.4	5.1	2.9	1.7	1.8	22.2
D 4.0 m/s	1.9	3.0	1.2	2.3	7.3	5.2	2.0	1.2	24.1
D 8.0 m/s	0.7	1.6	0.3	0.7	3.8	4.0	1.6	0.3	13.0
F 1.5 m/s	3.9	6.1	4.3	4.1	5.6	3.0	2.0	2.4	31.4
F 4.0 m/s	1.2	2.4	0.7	0.6	2.2	1.2	0.6	0.3	9.2
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.9	15.7	9.1	11.0	24.0	16.5	7.8	6.0	100.0

Ypenburg							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.71	0.95	2.41	2.58	0.00	0.00	7.65
016-045	1.65	1.00	1.81	1.33	0.00	0.00	5.78
046-075	2.72	1.14	2.36	2.82	0.00	0.00	9.04
076-105	2.20	0.98	1.66	1.82	0.00	0.00	6.65
106-135	1.74	0.77	1.32	1.06	0.00	0.00	4.90
136-165	0.88	0.73	1.10	0.73	0.00	0.00	3.43
166-195	0.77	0.95	2.19	2.08	0.00	0.00	5.98
196-225	1.10	1.14	3.41	5.11	0.00	0.00	10.75
226-255	1.51	1.26	3.54	7.41	0.00	0.00	13.73
256-285	2.34	1.40	3.76	8.39	0.00	0.00	15.90
286-315	1.42	0.76	2.38	3.35	0.00	0.00	7.90
316-345	1.53	0.88	2.46	3.42	0.00	0.00	8.29
Total	19.56	11.95	28.40	40.09	0.00	0.00	100.00
Night	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.00	1.22	1.42	0.77	0.67	2.34	6.42
016-045	0.00	1.62	1.67	0.90	1.36	3.05	8.60
046-075	0.00	1.56	2.41	2.00	1.72	3.69	11.37
076-105	0.00	1.22	1.40	0.97	0.75	2.19	6.52
106-135	0.00	1.05	1.15	0.49	0.45	1.49	4.63
136-165	0.00	1.05	1.16	0.73	0.35	1.29	4.57
166-195	0.00	1.30	2.34	2.06	0.61	1.30	7.60
196-225	0.00	1.25	4.16	5.07	1.16	1.64	13.27
226-255	0.00	1.84	3.31	4.88	1.03	2.69	13.74
256-285	0.00	1.49	2.36	4.25	0.56	1.85	10.50
286-315	0.00	0.76	1.54	2.68	0.42	0.97	6.36
316-345	0.00	1.03	1.78	1.86	0.50	1.25	6.42
Total	0.00	15.38	24.69	26.62	9.58	23.74	100.00

Ypenburg									
Day	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	2.5	3.8	2.8	1.3	1.5	2.7	2.6	2.4	19.6
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	1.5	1.6	1.3	1.2	1.6	2.0	1.5	1.4	11.9
D 4.0 m/s	3.0	3.2	2.2	2.2	4.5	5.4	4.3	3.7	28.4
D 8.0 m/s	2.6	3.7	2.0	1.8	6.2	11.6	7.5	4.7	40.1
F 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	9.6	12.4	8.2	6.4	13.7	21.7	15.9	12.1	100.0
Night	**N-NO**	**NO-O**	**O-ZO**	**ZO-Z**	**Z-ZW**	**ZW-W**	**W-NW**	**NW-N**	**Total**
B 1.5 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 4.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
B 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D 1.5 m/s	2.2	2.2	1.7	1.7	1.9	2.6	1.5	1.6	15.4
D 4.0 m/s	2.4	3.1	1.8	2.3	5.3	4.5	2.7	2.5	24.7
D 8.0 m/s	1.3	2.5	1.0	1.8	6.1	7.0	4.8	2.2	26.6
F 1.5 m/s	4.2	4.8	2.6	1.9	2.3	3.6	1.9	2.4	23.7
F 4.0 m/s	1.7	2.1	0.8	0.7	1.5	1.3	0.7	0.8	9.6
F 8.0 m/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	11.8	14.6	7.9	8.4	17.1	19.0	11.6	9.6	100.0

Appendix 4.C Commentary

4.C.1 Outflow models

Table 4.1 gives the correlation between the LOC and the model to be used, making a number of choices:

- The modelling of a totally ruptured vessel filled with compressed gas and (non-boiling) liquid is in agreement with the information provided in the 'Yellow Book', Section 2.5.1.
- The continuous releases of vessels, tanks and transport units cover several LOC's, namely the 10-min release and the holes with effective diameters of 10 mm as well as the largest connection in the liquid phase. It is selected to model the release as a hole in the vessel wall with a sharp orifice (C_d = 0.62), as this is the most appropriate way to describe the rupture of small instrumentation pipes in the vessel wall, and the loss of containment due to external impact and a welding rupture. A rounded orifice with C_d = 0.95 to 0.99 might be more appropriate for modelling the continuous release of the largest connection in the liquid phase for transport units However, for simplicity only one type of orifice with corresponding C_d values has been selected. The value of C_d is in agreement with the recommendations in the 'Yellow Book' and is almost equal to the value given in [IPO], C_d = 0.6.
- The release from a leak in a pipeline is modelled as a stationary one. The pressure upstream is assumed to be kept constant due to the presence of a large upstream vessel or of compressors/pumps.
- The default value for the wall roughness, ε, is the same as for commercial steel, as listed in the 'Yellow Book' (Table 2.2). The value is intermediate, falling between the value for bronze, lead and glass (ε = 1.5 μm) and the value for cast iron (ε = 250 μm).
- The models in the 'Yellow Book' for release from the liquid phase assumes that pure liquid flows out of the vessel, i.e. flashing of liquid takes place outside the vessel. Some integrated risk models allow flashing in the orifice. The assumption of liquid flow without flashing in the orifice is consistent with the value assumed for C_d, i.e. C_d = 0.62. In some circumstances the modelling of flashing in the orifice can be more appropriate. The modelling of flashing in the orifice should be well motivated.
- The location of the hole is determined by the specific design of the tank or vessel. Important aspects to be considered are e.g. the position of the connections to the tank, the position of relief devices and the distribution of dangerous substances within a column. It might not be worthwhile to use a number of release positions for each part of an installation. In generic studies, no specific information is available. Hence, a default value is selected for the location of the hole. The default value should be near the geographical level at which people live, in order not to underestimate the risk. The value selected, i.e. one metre above ground, corresponds to the reference height for the calculation of effects.
- The release duration is limited to a maximum of 30 minutes:
  - For a continuous release of flammables, the maximum mass in the flammable cloud, i.e. the mass within the explosion limits, is usually reached within a few minutes. After this initial time period, the mass added to the flammable cloud is compensated by the dispersion of mass out of the flammable cloud. Therefore the release duration of flammables can be limited to 30 minutes.
  - For a release of toxics, the maximum exposure duration is set at 30 minutes (see Section 5.2.2). Therefore the release duration of toxics can be limited to 30 minutes.

- The direction of release is determined by the specific design of the tank or vessel. However, if no information is available, a default value is selected. The horizontal direction is in line with current practice. Models assume that release is parallel to the wind direction, so this direction is selected.
  Underground transport pipelines form an exception. As underground transport pipelines are embedded in soil, a vertical release is selected as default.
- The conditions for obstructed flow are taken from [IPO]. A calculation method for the length of the free jet L_j is added. The length of the free jet, L_j, is derived from the velocity of the gas in the free jet, according to equation 4.76 of the 'Yellow Book' [CPR14E]:

  $$u_c(s) / u_0 = C_u \times b_0 / s, \qquad (4.C.1)$$

  where:

  u_c velocity in the jet ($m\ s^{-1}$)
  u_0 velocity of the jet at the source ($m\ s^{-1}$)
  C_u empirical constant, equal to 12 (-)
  b_0 source radius (m)
  s co-ordinate along jet axis (m)

  This equation implies that the release is in a uniform quiescent atmosphere.

  The length of the free jet is calculated using the criterion that the velocity at the end of the free jet regime is comparable to the ambient wind velocity. The length of the free jet, L_j, is then defined as the position, s, where the velocity in the jet, $u_c(s)$, is equal to the ambient wind velocity u_{air}:

  $$L_j = C_u \times u_0 \times b_0 / u_{air} \qquad (4.C.2)$$

  where:

  C_u empirical constant, equal to 12 (-)
  u_0 velocity of the jet at the source ($m\ s^{-1}$)
  b_0 source radius (m)
  u_{air} ambient wind velocity ($m\ s^{-1}$)

  For a simple expression for the length of the free jet, independent of the meteorological situation, the ambient wind velocity is set to an average of 5 $m\ s^{-1}$.

  The modelling of an obstructed free jet, using a reduction of the impulse of the jet with a factor 4, is copied from [DNV98].

4.C.2 Blocking systems

The default values for the operation of the blocking system are taken from [IPO]. In [IPO], a distinction is made between failure upon demand of the blocking system, and failure upon demand of the blocking valves. The distinction is not well described for the three different types of blocking systems. Therefore the failure upon demand is described here as the failure of the blocking system as a whole. The closing time of the systems is based on the following considerations [IPO]:

- The closing time for an automatic blocking system is based on a fully automated gas detection system. The closing time of 2 min consists of:
  - 30 s for the gas to reach the detector;
  - 30 s for the closing signal from the detector to reach the closing valve;
  - 1 min to close the valves.
- The closing time for a remote controlled blocking system is based on an automated gas detection system. The closing time of 10 min consists of:
  - 30 s for the gas to reach the detector;
  - 30 s for the alert signal from the detector to reach the control room;
  - 7 min to validate the signal
  - 2 min to close the valves.
- The closing time for a hand-operated blocking system is based on a automated gas detection system. The closing time of 30 min consists of:
  - 30 sec for the gas to reach the detector;
  - 30 sec for the alert signal from the detector to reach the control room;
  - 7 min to validate the signal;
  - 15 min for the operator to go to the blocking valve and to make use of personal protective equipment;
  - 7 min to remove the security locks and to close the valves.

  It should be noted that the effect of a hand operated blocking system does not appear in the QRA, as the maximum duration of the outflow is equal to 30 min.

4.C.3 Repression systems

The application of a repression system is in line with [IPO], where it is explicitly stated that the effect of repression systems should be demonstrated and quantified. The repression systems considered in this section reduce the source term following a LOC. Other repression, like a sprinkler installation on a pressurised storage tank of LPG or the cooling of tank wagons in the vicinity of a fire systems, affect the probability of a LOC. The effects of these types of repression systems are discounted in the failure frequencies.

4.C.4 Pool evaporation

The default values in Table 4.2 and Table 4.3 are taken from the ‘Yellow Book’. Since the models to calculate pool evaporation are described in terms of circular pools, an effective pool radius is defined.

4.C.5 Time-varying release

The conversion of a time-varying release into one single release segment is included since a number of models are yet not able to handle multiple time segments. For flammables, a high release rate is selected as the effects of flammable gases are usually determined by the mass released in the first few minutes of the release. Hence, the release conditions of the first 20% of the mass is assumed to be decisive. For toxics, the effects are determined by the dose received in the total exposure duration. Hence, the outflow conditions should be more or less averaged over the total release duration. However, a weighing towards the higher release rates is necessary since the lethality of most toxics is more than linear in the concentration. Consequently, the conditions of the mass released in the second out of five time segments are assumed to be representative.

The modelling of the dispersion as independent steady-state releases is selected as a more conservative approach.

4.C.6 Modelling vapour cloud dispersion

The deposition of material can be modelled if data are available. However, often the models used do not consider deposition. Therefore deposition processes do not have to be considered in the dispersion calculation.

The default values for the roughness length are taken from the 'Yellow Book'.

The averaging time for flammables is short, as indicated in the 'Yellow Book'. The selection of the value is based on currently used values. The averaging time for toxics should be comparable to the exposure time and consequently to the release duration. If a large number of scenarios have to be processed, it is not worthwhile calculating each scenario with an individual averaging time. The averaging time for toxics is based on an exposure time of 10 minutes. This value is somewhat arbitrarily selected, i.e. between short release with exposure time in the order of 30 s - 60 s, and a long release with exposure time in the order of 30 min.

4.C.7 Release inside a building

The calculation of the release of substances from a building is based on the assumption that the concentration in the room where the release takes place is (almost) immediately in equilibrium with the new source term. Where this assumption is not correct, the concentration in the ventilation air, C_{vent}, has to be calculated with the differential equation:

$$V \times dC_{vent} /dt = Q_{in} - C_{vent} \times F, \qquad (4.C.3)$$

with V being the volume of the room in m^3 and Q_{in} the (time-dependent) source term inside the building. The release to the atmosphere, Q_{out}, is equal to $Q_{out} = C_{vent} \times F$.

The influence of the building wake was recently described in [Wi98]. The equation for the concentration in the recirculation zone is also described in [IPO]. In [IPO], the length of the recirculation zone is determined by the height of the building. In [NM86], the length of the recirculation zone is determined by the minimum of either the height or the width of the building. The formulation in [NM86] is used here. The default value K = 1, being the value for the yearly averaged concentration used for buildings in general is applied here.

4.C.8 Fires and plume rise

The 'Yellow Book' uses the Briggs formula for plume rise. The formulas in the 'Yellow Book' were originally derived for releases from conventional stacks and are probably not applicable to open fires. Analogous to the CPR-15 method, the concentration of toxic substances at ground level is therefore assumed to be low due to the plume rise and the dilution in the atmosphere. Lethal effects are therefore not to be expected. However, if a model is available to calculate the concentration at ground level for open fires, it is recommended to use it to calculate the plume trajectory.

4.C.9 Ignition

The data on direct ignition and the probability of a BLEVE are taken from [IPO].
For stationary installations, it is assumed that 70% of the instantaneous releases with direct ignition is caused by heating due to a pool fire underneath the tank or heat radiation from a fire nearby. The result is a BLEVE and a fire ball. Since the excess heat of the fire results in an excess pressure in the tank, the total inventory of the tank is incorporated in the BLEVE.
It is assumed that 30% of the instantaneous releases with direct ignition is due to other causes. Since no excess heat is available, a vapour cloud and a liquid pool may be formed. Direct ignition of the vapour cloud results in a flash fire and explosion (see Section 4.8), whereas direct ignition of the liquid pool results in a pool fire.

Recently, the fraction that will remain airborne has been reviewed [VITO97]. The review indicates that the fraction that will remain airborne is probably larger than twice the flash fraction and recommends using the relationships given in Table 4.8 for instantaneous releases. Hence, the relationships are copied here.

The pressure at failure of the vessel should be equal to 1.21 × the opening pressure of the relief device or, if no relief device is present, should be equal to the test pressure of the vessel.

The effect of a fireball depends on the fraction of the generated heat radiated by the fireball [CPR14E]. The fraction of the heat radiated is a number between 0.2 and 0.4 and is a function of the vapour pressure of the flammable material inside the vessel at failure. Consequently, the burst pressure of the vessel is an important factor.

Table 7.1 of the 'Yellow Book' gives characteristic pressure and temperature at failure [CPR14E]. If failure is due to causes like corrosion of the vessel, erosion of the vessel, material defect, external impact or fatigue of vessel, the pressure at failure is the storage or working pressure. If the failure cause is external fire, the pressure at failure is equal to 1.21 × the opening pressure of the safety valve. Causes like overfilling or overheating in combination with failure of the safety valve results in failure at the design pressure × a safety factor (= usually 2.5).

The effect of the pressure on the effect distances of a BLEVE are shown in Figures 4.C.1 and 4.C.2 for storage of 100 tonnes propane and butane, respectively. The pressures at failure shown are:

- the storage pressure at ambient temperature, 282 K;
- 1.21 × the relief pressure of the safety valve; the relief pressure is set equal to the saturated vapour pressure at 308 K;
- the test pressure; the test pressure is calculated by multiplying the overpressure at 308 K + 1.7 bar by a factor of 1.4. The relief pressure should always be less than the test pressure [CPR8-3];
- the pressure corresponding with the maximum fraction of heat radiated, 0.4; this pressure is equal to 34 bar or higher.

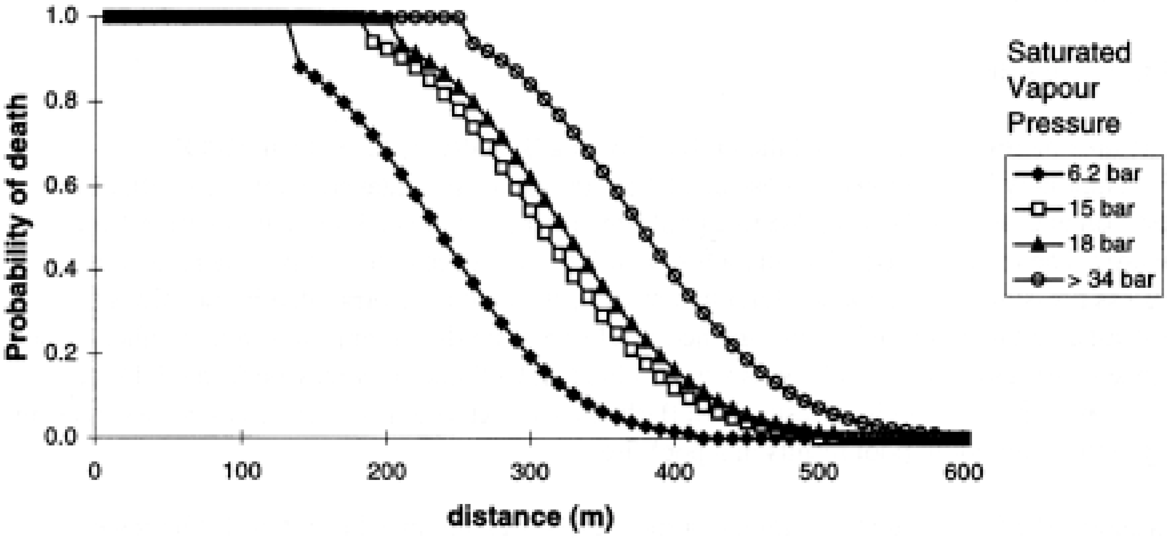

Figure 4.C.1 The probability of death as a function of the distance for a BLEVE of a storage tank containing 100 tonne propane. Indicated are the storage pressure at ambient temperature (6.2 bar), 1.21 × the relief pressure of the safety valve (15 bar), the test pressure (18 bar) and the curve corresponding with maximum fraction of heat radiated (> 34 bar).

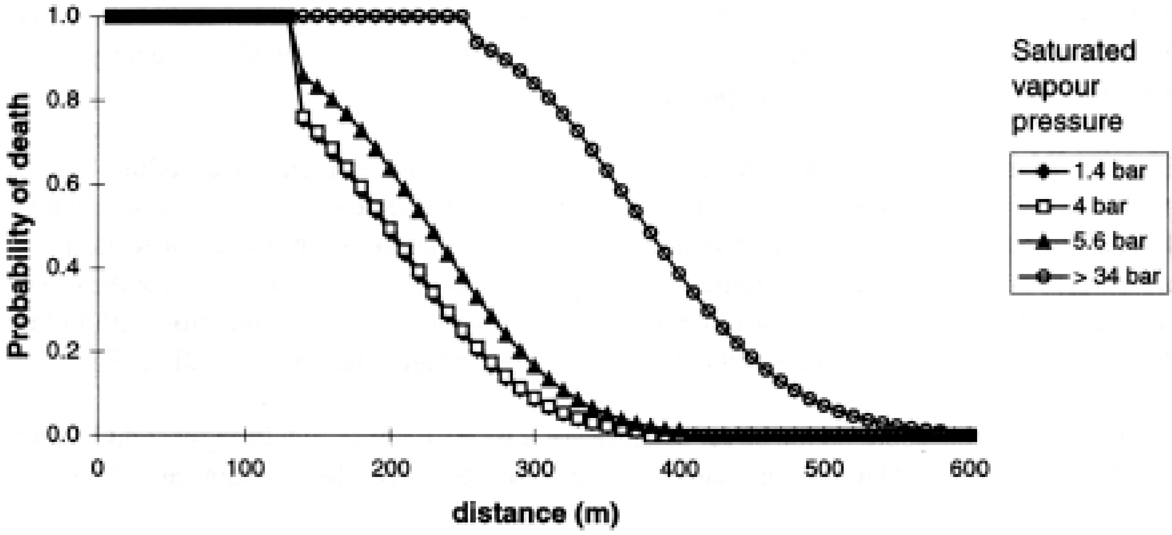

Figure 4.C.2 The probability of death as a function distance for a BLEVE of a storage tank containing 100 tonne butane. Indicated are the storage pressure at ambient temperature (1.4 bar), 1.21 × the relief pressure of the safety valve (4.0 bar), the test pressure (5.6 bar) and the curve corresponding with maximum fraction of heat radiated (> 34 bar).

Frequently, the storage or working pressure is used in the effect calculations of a BLEVE. However, it is postulated that a BLEVE is caused by weakening of the tank vessel wall due to a pool fire underneath a tank or due to a fire nearby. Hence, the pressure at failure is set equal to 1.21 × the relief pressure of the safety valve. If no safety valve is present, the pressure at failure is set equal to the test pressure of the tank.

For delayed ignition, in [IPO], a distinction is made between stationary installations and transport units at an establishment. For stationary units, delayed ignition is always equal to (1 – direct ignition), whereas for transport units non-ignition is defined as a probability. There is no argument for this distinction.

The free field calculation results in risk contours that are independent of the environment. As a conservative approach, the delayed ignition should be modelled to give the maximum effects. In general, this is an iterative process since the mass in the cloud decreases as the distance travelled increases. To facilitate the calculations, it is decided that delayed ignition occurs at maximum cloud extent. A definition of the maximum cloud extent would be the maximum amount of mass within the LFL contour. However, using this definition, an instantaneous release would ignite immediately at the release location. It is therefore decided to use as a definition of maximum cloud extent: the maximum area of the LFL cloud footprint.

In principle, an Individual Risk calculation should be done with calculation method B, the free field calculation. However, on special occasions it is allowed to use calculation method A. Since criteria to use calculation method A have not been defined yet, the decision has to be made by the competent authorities.

It has been decided to model substances that are both toxic and flammable as flammables using the probability of direct ignition, and otherwise as toxics. However, substances like ammonia are usually modelled as purely toxics. Therefore substances with low reactivity are to be modelled as purely toxics.

To determine the probability of ignition, the approach described in [DNV96, AM94] is used (see Appendix 4.A). It should be noted that the figures are not completely reliable and some care has to be taken. Therefore, using a time-independent probability of ignition is not excluded, in which case the value for the passage of the cloud is arbitrarily set to 1 min.

[IPO] gives some figures for the (time-independent) probability of ignition. A comparison with the figures used in [AM94] is given in Table 4.C.1; here the length of a road element is set equal to 100 m, and the velocity of a vehicle to 50 km/h.

Table 4.C.1 Ignition probability as given in [IPO] and [AM94]

Source	**IPO**	**[AM94]**
industrial site	0.9	0.9
process installations	0.5	0 - 0.9
road, N < 50 veh. per hour	0.5	0 - 0.1
road, N > 50 veh. per hour	1	0.1 - 1

4.C.10 Effects of ignition of a vapour cloud

Following the delayed ignition of an unconfined vapour cloud, one event occurs which has the characteristics of both a flash fire and an explosion. The range of possible events can be assumed to be divided in two separate classes, namely a pure flash fire and a pure explosion. A reasonable estimation seems to be a 60% – 40% division [DNV96]. However, in the study called ‘LPG-Integraal’ a different division is used, namely 30% – 70% division for a flash fire and explosion, respectively [TNO83]. As these figures are uncertain, one of these values is selected arbitrarily.

The effect distances to the peak ‘side on’ overpressure contours of 0.1 barg and 0.3 barg, $R_{0.1\ barg}$ and $R_{0.3\ barg}$ respectively, are calculated using the Multi-Energy Method [CPR14E]. The combustion energy scaled distances are derived from Figure 5.8A in [CPR14E], using the highest value of the blast strength, 10. The values of the combustion energy scaled distances corresponding to 0.1 barg and 0.3 barg, $r'_{0.1\ barg}$ and $r'_{0.3\ barg}$ respectively, are estimated as $r'_{0.1\ barg} = 3$ and $r'_{0.3\ barg} = 1.5$.

The results of the Multi Energy Method using the highest value of the blast strength are comparable to a TNT equivalent method with a TNT-equivalence factor of 20% in the overpressure range of 10 to 100 kPa [CPR14E]. Previously, distances to overpressure contours are calculated as $R_{0.3} = 0.03 \times (\eta \times E)^{1/3}$ and $R_{0.1} = 0.06 \times (\eta \times E)^{1/3}$ [CPR14]. The TNT-equivalence factor, η, was set equal to 10%. Using a default value of 0.08 for the fraction of the mass in obstructed regions would therefore reproduce the distances used previously.

4.C.11 Rupture of vessels

The blast waves and high velocity fragments following the rupture of a pressurized vessel can lead to lethal effects outside the plant area. However, these effects are not considered in the QRA for the following reasons:
- The effect of the physical blast wave is expected not to be important at larger distances, i.e. outside the plant area, relative to the toxic or flammable effects.
- The probability of being hit by a fragment outside the plant area is very low.

Therefore these effects will not to be considered in the QRA.

4.C.12 Meteorological data

In contrast to [IPO] it was decided not to define the exact wind speed, but to use the categories low, medium and high. In this way the transformation of data can be avoided if an available wind speed distribution does not exactly match the classification used in [IPO].

In the Manual [IPO] it was decided to use the closest meteorological station. However, the closest meteorological station is not necessarily the most representative. Especially for a site near the coast, it is better to use a meteorological station near the coast instead of an inland station.

The frequency distributions of a number of meteorological stations are listed in Appendix 4.B. The data are compiled from [KNMI72], are based on the Pasquill classification of stability using routine meteorological observations as wind speed, cloud cover and time of day and are used in QRAs up till now. Recently, a new classification method of stability is proposed, resulting in a reduced frequency of neutral conditions [NNM98]. It is strongly recommended to use frequency distributions based on the new classification method when statistical data are available. However, long-term statistical data may not yet be available for the meteorological stations. The use of average data over the Netherlands or the use of data of weather stations relatively far away may lead to discrepancies between the situation to be modelled and the data used.

The values in this manual for the meteorological parameters differ from the values listed in [IPO] in that they are more appropriate as yearly averaged values. The values are derived from [KNMI92]:

Ambient air temperature	equal to the yearly averaged value, 9.3 °C
soil/bund temperature	set equal to the ambient air temperature
Water temperature	set equal to the ambient air temperature
Ambient pressure	equal to the yearly averaged value, 1015.1 hPa
Humidity	equal to the yearly averaged value, 83%
solar radiation flux	equal to the average global radiation in a year (364,584 J cm^{-2}) divided by the time period of one year

In reality, a small difference, in the order of 1 °C, exists between the average soil temperature and the average air temperature. As the difference is small, it has been decided to set the various temperatures equal to one another.

5. MODELLING EXPOSURE AND DAMAGE

5.1 Introduction

Determination of the exposure and effects follows the release and dispersion of a dangerous substance in the environment. Since regulation is based on the probability of death, only lethal effects are relevant. This chapter will describe the calculation methods to determine the probability of death given the exposure and the fraction of the population for whom exposure is fatal. The following two parameters are used throughout this chapter to express the lethal effects:

- the probability of death, P_E, indicating the probability of an individual dying from exposure. The individual is assumed to be outdoors and to be unprotected. This parameter, P_E, is to be used in the calculation of the Individual Risk contours.
- the fraction of the population dying, F_E, indicating the fraction of the population dying at a certain location due to a given exposure. At least part of the population is protected by staying indoors and wearing protective clothing. For this reason, two values are used, $F_{E,\ in}$ and $F_{E,\ out}$, to denote the respective fractions of the population dying indoors and outdoors. The parameters, $F_{E,\ in}$ and $F_{E,\ out}$, are to be used in the calculation of the Societal Risk.

Probit functions are used to calculate the probability of death due to toxic substances and exposure to heat radiation at a given exposure. The use of probit functions is described in Section 5.2.1. The effects of toxic substances, fires and explosions are described in the Sections 5.2.2, 5.2.3 and 5.2.4, respectively. Section 5.3 presents the guidelines to calculate the population present in certain surroundings.

5.2 Damage modelling

5.2.1 Probit functions

The calculation of the Individual Risk and the Societal Risk involves calculating the probability of death of a person at a given exposure. The probability of death is calculated using probit functions. The relation between the probability of an effect, P, and the corresponding probit, Pr, is given by:

$$P = 0.5 \times \left[1 + erf\left(\frac{\mathrm{Pr} - 5}{\sqrt{2}}\right)\right] \tag{5.1}$$

where:

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2}\, dt \tag{5.2}$$

The relation between the probability of an effect, P, and the corresponding probit, Pr, is also given in Table 5.1.

The relation between the probability of an effect and the exposure usually results in a sigmoid curve. The sigmoid curve is replaced with a straight line if the probit is used instead of the probability, as shown in Figure 5.1.

Table 5.1 The probit, Pr, as a function of the probability, P

P	**0**	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**
0	-	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
0.1	3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
0.2	4.16	4.19	4.23	4.26	4.29	4.33	4.36	4.39	4.42	4.45
0.3	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
0.4	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
0.5	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
0.6	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
0.7	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
0.8	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
0.9	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33

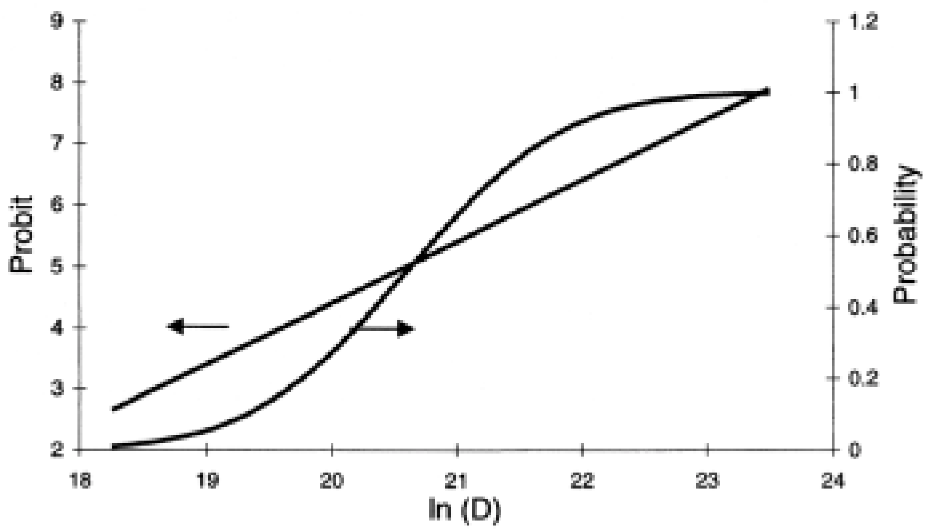

Figure 5.1 The probability, P, and the probit, Pr, as a function of exposure to ammonia. The exposure is represented by ln (D), with D the toxic dose (see Section 5.2.2). The figure shows how the sigmoid curve is replaced with a straight line if the probit is used.

5.2.2 Toxic exposure

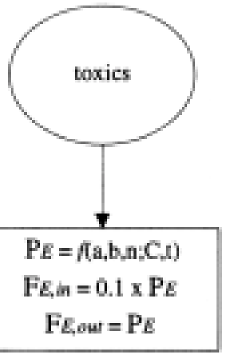

Figure 5.2 Calculation of the probability of death, P_E, and the respective fractions of the population dying indoors and outdoors, $F_{E,in}$ and $F_{E,out}$, due to exposure to a toxic cloud. The function f(a,b,n;C,t) is the probit function for exposure to toxic substances (toxics).

The probability of death due to exposure to a toxic cloud, P_E, and the fraction of people indoors and outdoors dying, $F_{E,in}$ and $F_{E,out}$, is given in Figure 5.2. The probability of death, P_E, is calculated with the use of a probit function and relation 5.1 in Section 5.2.1. The probit function for death due to toxic exposure is given by:

$$\mathrm{Pr} = a + b \times \ln (C^n \times t), \quad (5.3)$$

with:

Pr	probit corresponding to the probability of death	(-)
a, b, n	constants describing the toxicity of a substance	(-)
C	concentration	(mg m^{-3})
t	exposure time	(minutes)

Notes:

1. The value of the constant, a, depends on the dimensions of the concentration, C, and the exposure time, t. The dimensions of the concentration and exposure time must correspond to the value of the constant, a, in the probit function.

2. The probit is a function of the toxic dose to an individual. The toxic dose, D, is equal to $D = C^n \times t$ if the concentration, C, is constant during the time of exposure, t. If the concentration is not constant in time, the toxic dose is calculated as $D = \int C^n \, dt$; the probit, Pr, should be calculated correspondingly.

3. The exposure time, t, is limited to a maximum of 30 minutes, starting from the arrival of the cloud. The arrival of the cloud can be defined as the moment when the probability of death, P_E, exceeds 1%.

4. Staying indoors reduces the toxic dose since the concentration indoors is lower than the concentration outdoors during cloud passage. This effect is accounted for by a generic factor 0.1 in the fraction of people dying indoors. Instead of using the generic factor 0.1, one may use the ventilation rate of dwellings to calculate the dose indoors and the fraction of people dying indoors. The method is described in [CPR16]. It should be noted that the dose indoors strongly depends on the passage time of the cloud, the ventilation rate during the passage of the cloud and the ventilation after the passage of the cloud.
   - The passage time of the cloud varies with distance from the source and is different for each LOC. Hence, the dose indoors has to be calculated for each LOC and at each distance.
   - The ventilation rate depends strongly on parameters like the type and age of the dwellings, weather conditions and the opening and closing of windows. If no specific information is available, a ventilation rate of 1 h^{-1} and no adsorption should be used.
   - People are not expected to know when the cloud has passed. Consequently, the ventilation rate after the passage of the cloud is equal to the ventilation rate during the passage of the cloud and the lag-time between cloud passage and the start of total ventilation by opening the windows is high, i.e. minimally 0.5 hours.
   - The maximum exposure time indoors is 30 minutes. The lag-time between cloud passage and the start of total ventilation by opening the windows is therefore maximally 0.5 hours.

5. The values for the constants describing the toxicity of a substance, a, b and n, are given for a number of substances in Table 5.2. The toxic constants of these and a number of other substances are also given in the database of substances [RIVM99].

   The probit function of a toxic substance not listed in Table 5.2 or in the database of substances [RIVM99] has to be determined on the basis of acute toxicity data of animals. The procedure to derive the constants a, b and n from toxicity data is described in [CPR16]. However, expert advice is needed when using toxicity data to derive the probit function.

Table 5.2 Values for the constants describing the toxicity of a substance, a, b and n. The values are valid for the probit function with the concentration, C (mg m^{-3}) and the exposure time, t (min).

Substance	a	b	n
Acrolein	– 4.1	1	1
Acrylonitrile	– 8.6	1	1.3
Allylalcohol	– 11.7	1	2
Ammonia	– 15.6	1	2
Azinphos-methyl	– 4.8	1	2
Bromine	– 12.4	1	2
Carbon monoxide	– 7.4	1	1
Chlorine	– 6.35	0.5	2.75
Ethylene oxide	– 6.8	1	1
Hydrogen chloride	– 37.3	3.69	1
Hydrogen cyanide	– 9.8	1	2.4
Hydrogen fluoride	– 8.4	1	1.5
Hydrogen sulfide	– 11.5	1	1.9
Methyl bromide	– 7.3	1	1.1
Methyl isocyanate	– 1.2	1	0.7
Nitrogen dioxide	– 18.6	1	3.7
Parathion	– 6.6	1	2
Phosgene	– 10.6	2	1
Phosphamidon	– 2.8	1	0.7
Phosphine	– 6.8	1	2
Sulphur dioxide	– 19.2	1	2.4
Tetraethyllead	– 9.8	1	2

5.2.3 Fire

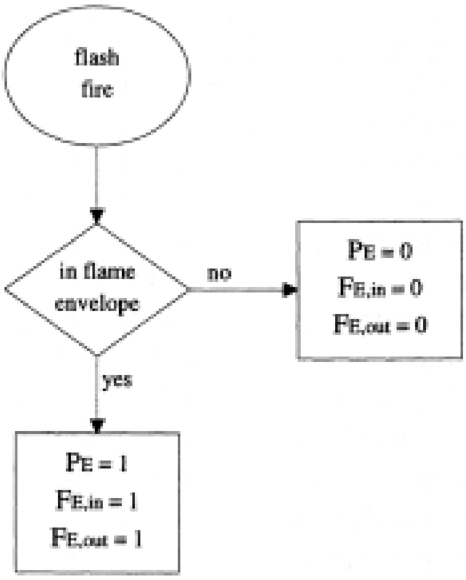

Figure 5.3 Calculation of the probability of death, P_E, where the respective fractions of the population dying indoors and outdoors are $F_{E,in}$ and $F_{E,out}$ on exposure to a flash fire.

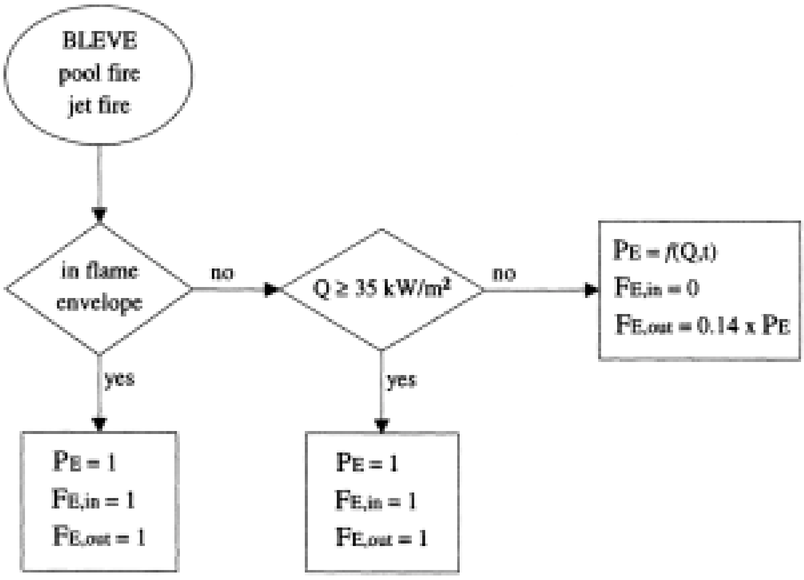

Figure 5.4. Calculation of the probability of death, P_E, where the respective fractions of the population dying indoors and outdoors are $F_{E,in}$ and $F_{E,out}$, for exposure to a BLEVE, pool fire and jet fire. The probit function for heat radiation is f(Q,t).

The probability of death due to a flash fire, P_E, and the respective fractions of people dying indoors and outdoors, $F_{E,in}$ and $F_{E,out}$, is given in Figure 5.3. The probability of death due to a BLEVE, jet fire or pool fire, P_E, and the respective fractions of people dying indoors and outdoors, $F_{E,in}$ and $F_{E,out}$, is given in Figure 5.4. The probability of death due to the exposure to heat radiation is calculated with the use of a probit function and relation 5.1 in Section 5.2.1. The probit function for death due to heat radiation is given by:

$$Pr = -36.38 + 2.56 \times 1n\,(Q^{4/3} \times t), \qquad (5.4)$$

with:

Pr	probit corresponding to the probability of death	(-)
Q	heat radiation	($W\ m^{-2}$)
t	exposure time	(s)

Notes:

1. The probit function for death due to heat radiation is currently under review. The function may be modified in a new edition of the ‘Green Book’ [CPR16].

2. The flame envelope of a flash fire is equal to the LFL contour at the time of ignition.

3. The exposure time, t, is equal to the duration of the fire. However, the exposure time is limited to a maximum of 20 s.

4. It is assumed that people indoors are protected from heat radiation until the building catches fire. The threshold for the ignition of buildings is set at 35 $kW\ m^{-2}$. If the building is set on fire, all the people inside the building are assumed to die. Hence, $F_{E,in}$ = 1 if the heat radiation, Q, exceeds 35 $kW\ m^{-2}$ and $F_{E,in}$ = 0 if the heat radiation, Q, is less than 35 $kW\ m^{-2}$.

5. For the Societal Risk calculation, it is assumed that people outdoors are protected from heat radiation by clothing until it catches fire. The protection of clothing reduces the number of people dying by a factor of 0.14 compared to no protection of clothing. The threshold for the ignition of clothing is set at 35 $kW\ m^{-2}$ and people die if clothing catches fire at this threshold. Hence, $F_{E,out}$ = 1 if the heat radiation, Q, exceeds 35 $kW\ m^{-2}$ and $F_{E,out} = 0.14 \times P_E$ if the heat radiation, Q, is less than 35 $kW\ m^{-2}$.

5.2.4 Pressure effects for a vapour cloud explosion

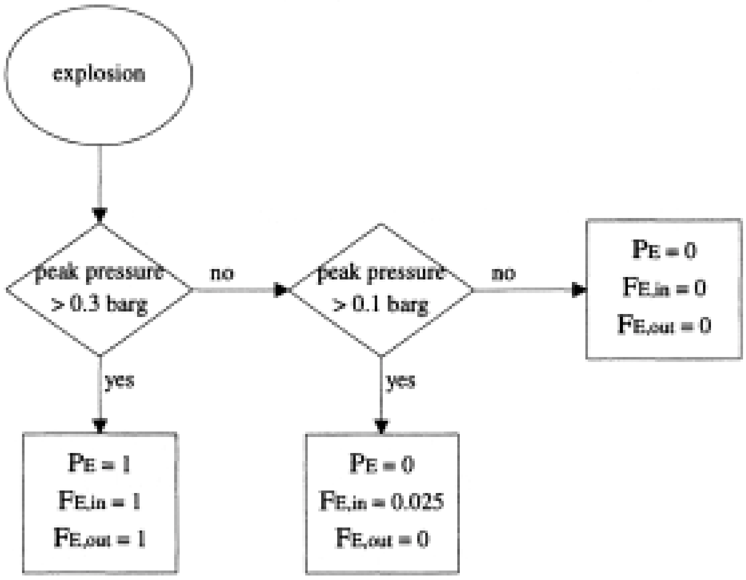

Figure 5.5 Calculation of the probability of death, P_E, and the respective fractions of the population dying indoors and outdoors, $F_{E,in}$ and $F_{E,out}$ from exposure to a blast/explosion.

The probability of death due to an explosion, P_E, and the respective fractions of people dying indoors and outdoors, $F_{E,in}$ and $F_{E,out}$, are given in Figure 5.5. It should be noted that the values given here are only applicable to a vapour cloud explosion. The values are not applicable to the detonation of explosives due to differences in the duration of the blast.

5.3 Population

5.3.1 Survey of the population present

The presence of the population is important to the calculation of both the Societal Risk and the ignition probability. Therefore the presence of population in the environment should be surveyed. The following rules apply:

1. The present situation should be used to determine the population present. The population in future residential areas for which approved spatial plans exist should be taken into account. The population density in these areas has to be calculated on the basis of these plans. If no actual information is available, default values can be used for the population density in new residential areas [CPR16]. The accuracy of the information needed also depends on the purpose of the QRA.

2. The population in recreational areas should be taken into account. If the type of recreation depends on the season, discrete values for the population density should be used for different times of the year. If large groups of people are present during short time periods, as in stadiums, discrete values for the population density should be used for different time periods. However, if the fraction of the time that a large group of people is present is very

low, the use of discrete values can be omitted. This can, for example, happen if a stadium is used only for short periods of time throughout the year. As a guideline, if the product of the summed frequency of the relevant scenarios and the fraction of time that a large group of people is present is less than 10^{-9} per year, the presence of the large group can be ignored.

3. Current legislation has to be taken into account to decide whether people present in e.g. industrial areas, offices, hospitals and schools, on (other) industrial sites and motorways should be taken into account[a]. Inclusion or exclusion of groups of people also depends on the purpose of the QRA.

4. The presence of population varies with time, as people travel out of the area to work, attend schools and the like. Therefore different values have to be used for the population during daytime and night-time. The following rules are applied to determine the presence of the population:
   - Daytime refers to the period from 8:00 to 18:30 MET, night-time to the period 18:30 - 8:00 MET.
   - In residential areas the fraction of the population present during daytime is 0.7. The fraction of the population present during night-time is 1.0. If schools and/or working places are present in the residential area, the presence of people in these locations should be taken into account.
   - In industrial areas the fraction of the population present during daytime is equal to 1.0. If work is also done in night shifts, the fraction of the population present during night-time is equal to 0.2, otherwise the fraction is set equal to 0.
   - In recreational areas the population present during daytime and night-time depends on the type of recreation.

In principle, the population data used should be as detailed as possible. In practice, it can be difficult to collect population data on a very detailed level. There are a number of sources available to supply information on the population, like the municipalities and the provinces. Information can also be obtained on a commercial basis. Geographical Information Systems can be useful in processing population data. The following types of data, in decreasing order of detail, may be available:

1. The location of each house, e.g. by counting the number of houses on a map. The population density is derived assuming a density of 2.4 persons per house. Please note that one building on a map, e.g. an apartment building, may consist of several houses.

2. The central point of a group of houses, e.g. from databases listing the centre of gravity of all houses having the same postal code. The population density is derived assuming a density of 2.4 persons per house. However, care should be taken if large apartment buildings are present, in which case, the centre of gravity of the postal code can be some distance from the location of the apartments.

[a] The regulation to include or exclude groups of people is given in the new AMvB.

3. If no information on the population density is available at all, e.g. if spatial plans are only known roughly, default values for the population density can be used. Default values for various types of areas are listed in [CPR16].

As the population in a residential area is based on an average population density, people on local roads are already included in the average population density.

5.3.2 Fraction indoors and outdoors

In the calculation of the Societal Risk, it is assumed that at least part of the population is protected by staying indoors and wearing protective clothing. Since different values are used for the fractions of the population dying indoors and outdoors, the respective fractions of the population present indoors and outdoors, $f_{pop, in}$ and $f_{pop, out}$, have to be set. Default parameter values are given in Table 5.3. The values are valid for residential and industrial areas unless other information is available. For recreational areas, the type of recreation determines the fraction of the population indoors and outdoors.

Table 5.3 Fraction of the population present indoors ($f_{pop, in}$) and outdoors ($f_{pop,out}$) for daytime and night-time, where daytime refers to 8:00 - 18:30 MET and night-time to 18:30 - 8:00 MET

	$f_{pop, in}$	$f_{pop, out}$
daytime	0.93	0.07
night-time	0.99	0.01

Appendix 5.A COMMENTARY

5.A.1 General

The relation between the probability of an effect, P, and the corresponding probit, Pr, in Table 5.1 is taken from [CPR16].

5.A.2 Toxic exposure

For toxic substances, the probit function for the probability of death is described in [CPR16]. The values in Table 5.2 for the toxic constants a, b and n are taken from [KO 24-2], with the exception of ammonia and phosgene. The probit function of ammonia is taken from [KO 59] and of phosgene from [KO 86]. For a number of substances two different probit functions are listed in [KO 24-2], one function assuming n = 1 and another assuming n = 2. In [CPR16] it is recommended to use the value n = 2 in cases where n is not known. Hence only the probit function with n = 2 is given here.

The exposure time, t, is limited to a maximum of 30 minutes, in agreement with [IPO]. A maximum exposure time needs to be set because the probit function shows that for continuous releases of small amounts of substances all humans will eventually suffer death if the exposure time is long enough. As this is obviously not to be expected, a maximum exposure time is defined. Why exactly 30 minutes is taken as the maximum exposure time is not known. This value is possibly based on time needed for evacuation and/or the time lapse before first aid is provided.

The exposure time indoors may be longer than the passage time of the cloud, depending on the ventilation rate of the building. The exposure time indoors is limited to 30 minutes and takes into account the opening of windows after the passage of the cloud.

The concentration of toxic substances indoors can be calculated using a ventilation model for the building. However, the calculation is quite elaborate and the concentration indoors depends, among other aspects, on the specific meteorological conditions and the ventilation regime. Furthermore, the concentration inside the building is not uniform but varies from room to room, depending on the ventilation within the building [TNO98a]. Despite these difficulties, a ventilation model can be used to estimate the concentration inside a building. The use of a ventilation model is described in [CPR16]. Default parameter values are ‘no adsorption’ and a ‘ventilation rate of 1 h^{-1}’ (in line with the data in [CPR16]). The ventilation rate is assumed to be unchanged after the passage of the cloud and the maximum time of exposure to be 30 minutes. If the passage time of the cloud is relatively short, the dose reduction can then be estimated using a lag-time of 0.5 h between the passage of the cloud and the start of total ventilation.

In practice, while ventilation models are rarely used in a QRA, a generic reduction factor is used. [IPO] applies a reduction factor of 0.1 to the total population present, indoors and outdoors. The fraction of people dying is presented separately for the population indoors and outdoors.

- The population outdoors is not protected, so no reduction factor is applied to $F_{E, out}$.
- People indoors are protected. A reduction factor of 0.1 is applied to $F_{E, in}$. During daytime, 7% is assumed to be outdoors. A reduction factor of 0.1 in daytime for the fraction of people dying indoors corresponds to a factor of 0.16 for the total population. During night-time,

almost all humans (99%) are assumed to be indoors (see Section 5.3.2), and only 1% outdoors. At night-time, a reduction factor of 0.1 for the fraction of people dying indoors leads to almost the same results as a factor of 0.1 for the total population. Furthermore, at night-time the effect distances are largest since stable weather conditions with low wind speeds prevail. Hence, it was decided to apply a reduction factor of 0.1 to $F_{E, in}$.

5.A.3 Fire

The probability of death due to a flash fire, BLEVE, jet fire or pool fire are are derived from [CPR16, IPO].

An alternative calculation method to the probit function is described in [KO 20-2], a damage area being defined. For example, the damage area of a flash fire is the flame envelope and the damage area of a BLEVE is the area in which heat radiation exceeds a level of 12.5 kW m^{-2}. In the damage area, the probability of death is defined separately for people remaining indoors or outdoors. It is advised not to use this method anymore, but rather the method described here [IPO, CPR16].

Inside the flame envelope the probability of death is equal to one due to the high level of heat radiation and the ignition of clothing and buildings. Outside the flame envelope of a flash fire the heat radiation is assumed to be low and the probability of death equal to zero. The effects of a BLEVE, jet fire and pool fire outside the flame envelope are determined by the heat radiation.

The flame envelope of a flash fire is equal to the LFL contour, i.e. expansion of the cloud during combustion is not considered.

The maximum exposure time is set equal to 20 s. It is assumed that people can flee to a safe place within 20 s. It should be noted that previously it was assumed that people can reach a safe place more easily in a built-up area and consequently the maximum exposure time in a built-up area was reduced to 10 sec in the Societal Risk calculation [IPO]. However, it was decided to set the maximum exposure time equal to 20 s everywhere to facilitate the calculations at establishments where both built-up and untilled areas exist in the surroundings.

In the Individual Risk calculation, the probability of death from heat radiation is calculated with the probit function for an unprotected individual. The protective effect of clothing is not considered in the Individual Risk calculation.

In the Societal Risk calculation, the protection of clothing is taken into account and the probability of death due to heat radiation is calculated for an individual outdoors wearing clothing. The protective effect of clothing is assumed to reduce the probability of death; a factor of 0.14 is applied [CPR16]. However, if clothing ignites, the probability of death is equal to one. The threshold for the ignition of clothing is equal to $Q^2 \times t = 2.5 \times 10^4$ kW^2 m^{-4} s [CPR16]. An exposure time of 20 s results in a threshold of 35 kW m^{-2}. As it is assumed that buildings are set on fire at this level of heat radiation, this threshold for the ignition of clothing, 35 kW m^{-2}, is used in built-up areas as well.

The protective effect of buildings is considered explicitly in the Societal Risk calculation. Previously, two different approaches were used:

1. In QRAs for establishments, the protective effect of buildings was not considered. A reduction factor of 0.14 was applied to people indoors and outdoors [IPO].
2. In QRAs for marshalling yards, people died at heat radiation levels exceeding 40 kW m^{-2}. Below that level, people were considered safe inside buildings [SAVE97]. However, a reduction factor of 0.14 for people outdoors was not applied.

The modelling described here assumes that people are safe inside a building until the building catches fire. If the building is set on fire, all people inside are likely to succumb. Unfortunately, there was little information found on the threshold of ignition for buildings. Information indicates that [CPR16]:

- glass breaks at 4 kW m^{-2}
- the critical heat intensity, i.e. the radiation level where ignition occurs for long exposure times, is in the range of 25 - 35 kW m^{-2} for wood, textiles, fibreboard, hardboard and plastics. The critical heat intensity is in the order of 10 - 15 kW m^{-2} if ignition flames are present, e.g. fire sparks.
- ignition of upholstery occurs if the heat radiation, Q, and the exposure time, t, meets the condition $Q^2 \times t \geq 2.5 - 4.5\ 10^4$ kW^2 m^{-4} s. At an exposure time, t = 20 s, the lowest value corresponds to Q ~ 35 kW m^{-2}.

In view of this information, the threshold of the ignition of buildings is set to 35 kW m^{-2}.

A sample calculation for the effects of a BLEVE of 100 tonne LPG is shown in Figure 5.A.1.

A large fraction of the people are usually assumed to be indoors (see Section 5.3.2). It is therefore to be expected that for establishments the calculation method described here will result in a reduction in the Societal Risk relative to the calculation method used previously. For marshalling yards, the effect is assumed to be small. On one hand, the increase in the threshold radiation level from 35 kW m^{-2} to 40 kW m^{-2} will increase the Societal Risk. On the other hand, the factor 0.14 for people outdoors will decrease the Societal Risk.

It should be noted that a BLEVE also leads to blast effects. These effects are currently not included in the QRA calculation. The 'side-on' peak overpressure of the blast wave can be calculated with the method described in Chapter 7 of the 'Yellow Book' [CPR14E]. TNO has made a number of sample calculations to determine the blast effects relative to the heat radiation effects [TNO98d]. Results are shown in Figure 5.A.2, where distances to various pressure and radiation levels are shown as a function of tank inventory:

1. 0.03 bar overpressure, corresponding to the critical overpressure causing windows to break;
2. 0.1 bar overpressure, corresponding to 10% of the houses severely damaged and a probability of death indoors equal to 0.025 (see Section 5.2.4);
3. radius of the fireball, corresponding to 100% lethality
4. heat radiation equal to 35 kW m^{-2}, corresponding to the heat intensity at which people indoors are fully protected.

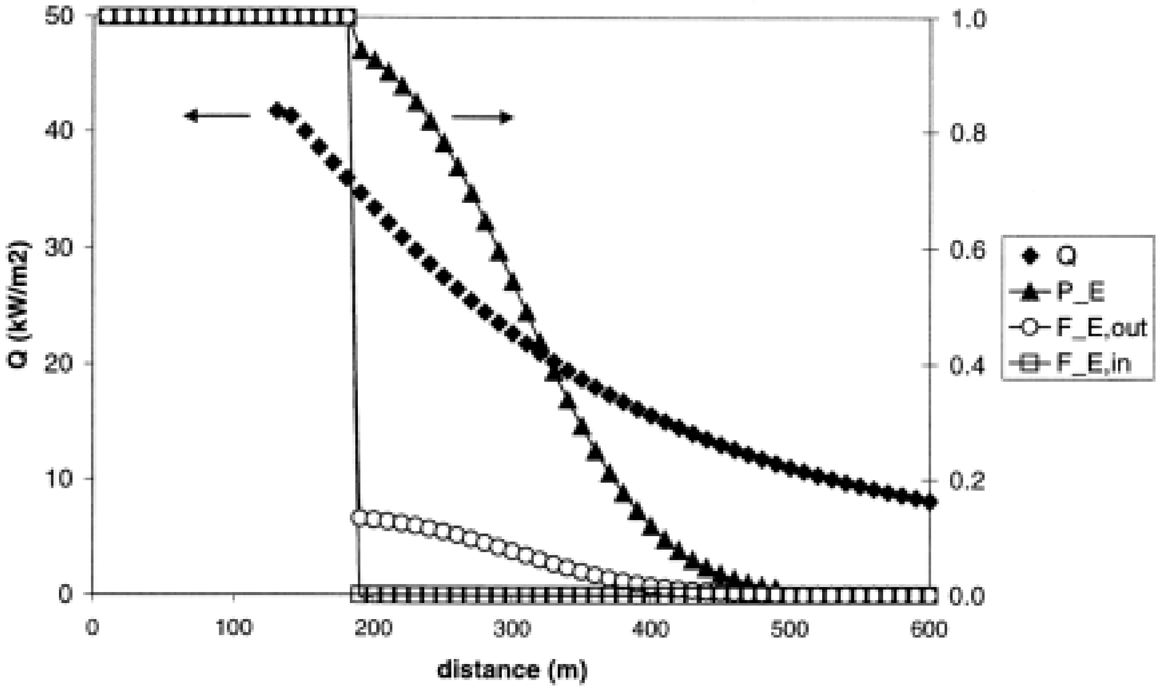

Figure 5.A.1 *Example calculation of a BLEVE of 100 tonne propane (burst pressure 15 bar). The exposure time is set at the maximum value of 20 s. Indicated are heat radiation, Q, probability of death,* P_E*, fraction of people dying outdoors,* $F_{E,out}$*, and fraction of people dying indoors,* $F_{E,in}$*.*

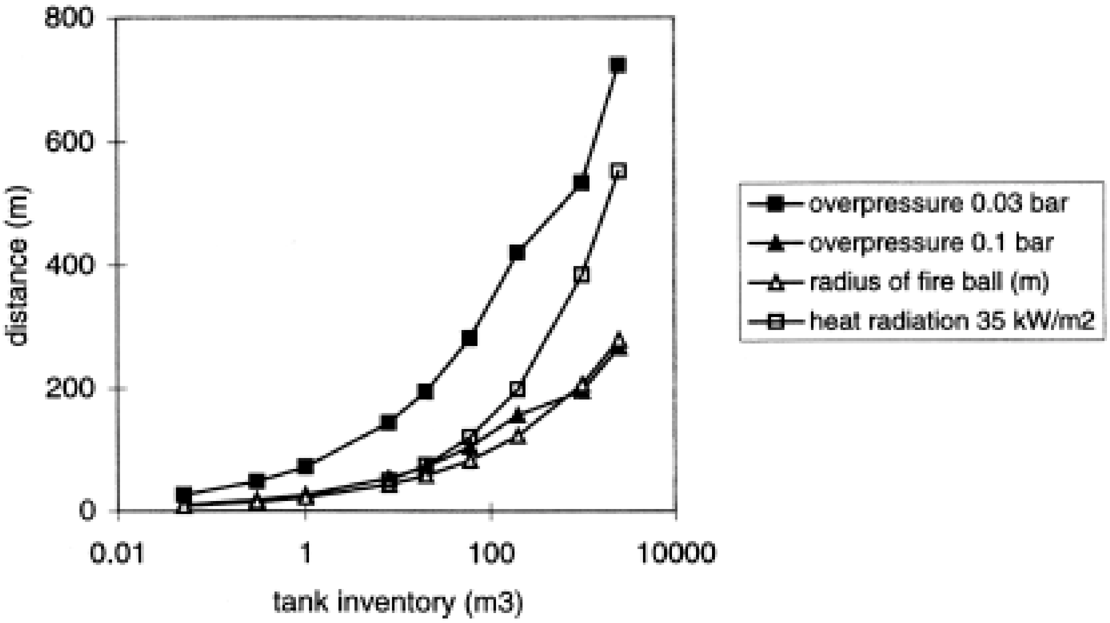

Figure 5.A.2 *Distances to various effect levels of a BLEVE as a function of tank inventory [TNO98d]. Indicated effect levels are the radius of the fireball, heat radiation equal to 35 kW* m^{-2} *and overpressure levels of 0.1 bar and 0.03 bar.*

The results show that for individual risk calculations, the pressure effects of a BLEVE can be ignored since the fire ball effects are dominant compared to overpressure effects on unprotected individuals. However, for societal risk calculations, caution is required. The results show that the blast effects at the distance corresponding with a heat radiation equal to 35 kW m^{-2} are between 0.1 bar and 0.03 bar overpressure. Consequently, breakage of windows is likely to occur, leading to glass fragments and reduced protection. Furthermore, glass also partly transmits heat radiation, and may also break due to intense heat radiation. Since nowadays large wall surfaces are made of glass, especially in office buildings, it is questionable whether the assumption that people are fully protected indoors at heat radiation levels of 35 kW m^{-2} is valid.
The assumption that people indoors are fully protected if the heat intensity is less than 35 kW m^{-2} is therefore based on the following:

- people indoors are able to find shelter behind walls in a very short time
- people indoors do not suffer lethal effects from being hit by glass fragments.

Note that this last assumption agrees with the effects of overpressure as described in Section 5.2.4, where no lethal effects are expected below 0.1 bar overpressure.

5.A.4 Pressure effects

The probability of death, P_E, due to the exposure to pressure waves is calculated using three different zones, depending on the peak overpressure, P_{peak}. The values in Figure 5.5 are derived from the values given in [IPO].

The origin of the value 0.025 for the fraction of people dying indoors is not well established. The study ‘LPG-Integraal’ indicates that: (1) about 10% of the houses outside the cloud and inside the 0.1 barg contour are severely damaged and (2) about one out of eight persons present in a severely damaged house is killed [TNO83]. This would suggest a factor of $0.1 \times 0.125 = 0.0125$ for the fraction of people suffering death indoors, i.e. a factor of two less.

5.A.5 Population

The values on the presence of population are mainly extracted from [CPR16].

[CPR16] gives a range for the fraction of the population present during daytime (0.3 – 0.7); the maximum value is selected here.

The period corresponding with daytime is set at 8:00 - 18:30 MET. It corresponds to the period used in the meteorological data.

The recommended number of persons per house is derived from the total population and number of houses in the Netherlands [BR97].

The presence of large groups of people can be ignored if the product of the summed frequency of the relevant scenarios and the fraction of time that a large group of people is present is less than 10^{-9} per year. This criterion is derived from the presentation of the Societal Risk curve, since frequencies below 10^{-9} per year do not have to be shown in the Societal Risk curve (see Chapter 6).

The values of the respective fractions of the population present indoors and outdoors, $f_{pop,\,in}$ and $f_{pop,\,out}$, are also taken from [CPR16].

6. CALCULATION AND PRESENTATION OF RESULTS

6.1 Introduction

The results of a QRA are the Individual Risk and the Societal Risk.

- The Individual Risk represents the frequency of an individual dying due to loss of containment events (LOCs). The individual is assumed to be unprotected and to be present during the total exposure time, as indicated in Chapter 5. The Individual Risk is presented as contour lines on a topographic map.

- The Societal Risk represents the frequency of having an accident with N or more people being killed simultaneously. The people involved are assumed to have some means of protection, as indicated in Chapter 5. The Societal Risk is presented as an FN curve, where N is the number of deaths and F the cumulative frequency of accidents with N or more deaths.

This chapter describes a calculation method for the Individual Risk and the Societal Risk, followed by a presentation of the results.

6.2 Calculation of the Individual Risk and the Societal Risk

The methods for calculating the Individual Risk and the Societal Risk are described for toxic and flammable substances. Section 6.2.1 describes the definition of the grid, Section 6.2.2 the calculation method of the Individual Risk and Section 6.2.3, the method used to calculate the Societal Risk. The definition of ignition events is described in Section 6.2.4. A crucial step is the calculation of the probability of death and the fraction of people suffering death. The computation of these factors is explained for toxic and flammable substances in Sections 6.2.5 and 6.2.6, respectively.

The calculation procedure described here is used in a number of computer programs. The description does not cover all possible events but is mainly intended to illustrate the principles of the calculation. Among other possible calculation methods is the one presented here, which assumes that weather data are available in the form of frequency tables of weather classes and wind directions (see Chapter 4). A different approach would be to use Monte Carlo simulations of a large number of weather sequences.

Note:

1. The probability of death and the fraction of people suffering death should be calculated up to the level of 1% lethality.

6.2.1 Definition of the grid

The calculation of the Individual Risk and the Societal Risk starts with the definition of a grid over the area of interest, the calculation grid. The centre of a grid cell is called a grid point and the Individual Risk is to be calculated at each grid point separately. The size of the grid cell should be small enough not to influence the calculation results, i.e. the Individual Risk may not vary much within a grid cell. As a guideline, if the effect distances of the significant scenarios are less than or comparable to 300 m, the size of a grid cell should not be larger than 25 × 25 m. For effect distances of the significant scenarios larger than 300 m, a grid cell of 100 × 100 m can be used. If relevant, a combination can be used, i.e. a small grid cell in the calculation up to 300 m and a large grid cell in the calculation starting from 300 m.

Next, the population within each grid cell has to be determined. The location of the population is determined following the guidelines in Chapter 5. Each location of population (e.g. a house or the central location of a group of houses) is assigned to a grid cell and the population is distributed uniformly over the entire grid cell, i.e. within a grid cell a uniform population density is assumed. It should be noted that a location may represent a large group of houses that extend over several grid cells. In these cases, it is advised to distribute the population over a representative number of grid cells.

Finally, a probability of ignition is assigned to each grid cell. All ignition sources in the grid cell are combined into a single ignition source located at the centre of the grid cell.

6.2.2 Individual Risk calculation

The Individual Risk is calculated at each grid point separately. The procedure to determine the Individual Risk at a single grid point is outlined in Figure 6.1. The frequency of an individual dying is calculated at a grid point for each Loss of Containment event (LOC), each weather class, each ignition event i (flammables only) and each wind direction separately. Next, the Individual Risk at the grid point is determined by adding up all contributions.

The various steps in the procedure to calculate the Individual Risk, *IR*, at a grid point:

1. Select a LOC, S. The failure frequency of the LOC is given by f_S (in y^{-1}). The various LOCs and the corresponding failure frequencies are described in Chapter 2.

2. Select a weather class, M, with probability P_M (-). The various weather classes are described in Section 4.10. Select a wind direction, φ, with conditional probability P_φ (-). The conditional probability, P_φ, is the probability of obtaining wind direction, φ, given the weather class, M. Often the product $P_M \times P_\varphi$ is given, being the probability of obtaining weather class, M, and wind direction, φ, simultaneously.

3. In case of the release of flammables, select an ignition event, i, with conditional probability P_i (-). The ignition events are described in Section 6.2.4.

4. Calculate the probability of death at the grid point, P_d, given the LOC, S, the weather class, M, the wind direction, φ, and ignition event, i (flammables). The calculation of P_d is elaborated in Section 6.2.5 for toxic substances and Section 6.2.6 for flammable substances. The reference height for the calculation of effects is equal to one metre.

5. Calculate the contribution, $\Delta IR_{S,M,\varphi,i}$ of the LOC, S, the weather class, M, the wind direction, φ, and ignition event, i, to the Individual Risk at the grid point:

$$\Delta IR_{S,M,\varphi,i} = f_S \times P_M \times P_\varphi \times P_i \times P_d \quad (y^{-1}) \qquad (6.1)$$

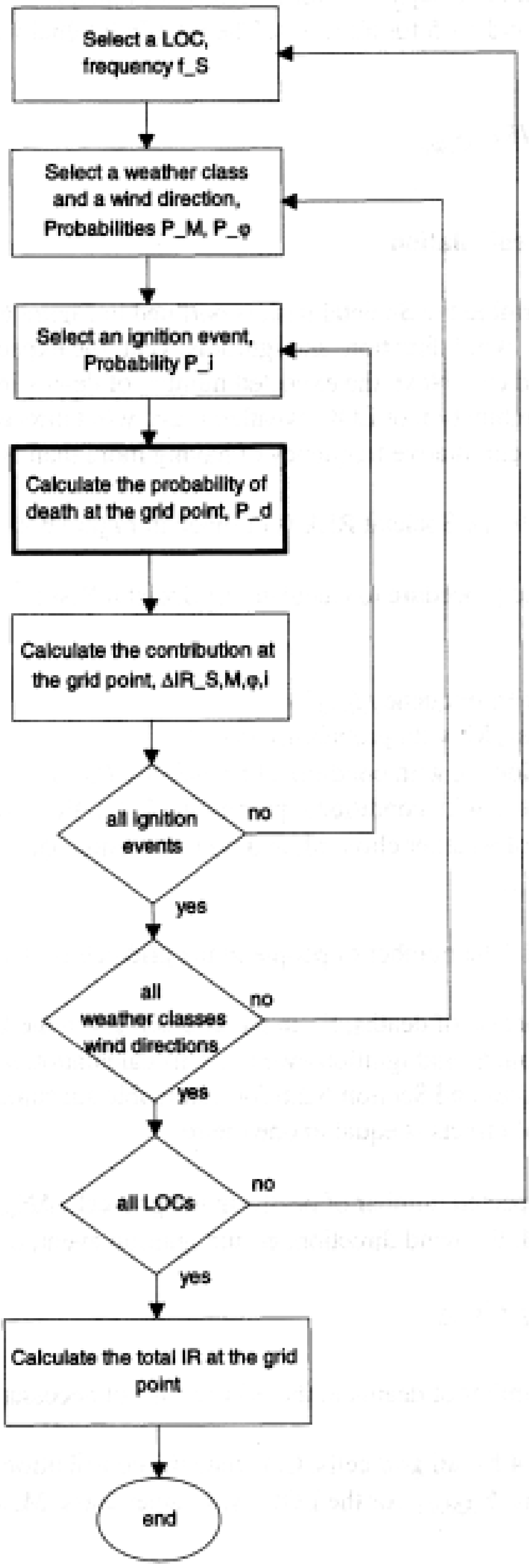

Figure 6.1 Procedure to calculate the Individual Risk, IR, at a grid point.

6. Repeat the calculation steps 3 - 5 for all ignition events, 2 - 5 for all weather classes and wind directions and 1 - 5 for all LOCs. The total Individual Risk, *IR*, at the grid point is calculated as:

$$IR = \sum_S \sum_M \sum_\varphi \sum_i \Delta IR_{S,M,\varphi,i} \qquad (6.2)$$

6.2.3 Societal Risk calculation

The procedure to determine the Societal Risk is outlined in Figure 6.2. For a single combination of LOC, weather class, wind direction, and ignition event, the expected number of deaths is calculated for each grid cell. Next, the expected number of deaths in all grid cells, N, is calculated for each combination of LOC, weather class, wind direction and ignition event separately. Finally, the cumulative frequency of having more than N deaths is determined.

The method to calculate the Societal Risk is outlined in Figure 6.2.

The various steps in the procedure to calculate the Societal Risk:

1. Select:
   - an LOC, S, with frequency f_S (y^{-1})
   - a weather class, M, with probability P_M (-)
   - a wind direction, φ, with conditional probability P_φ (-)
   - ignition event, i, with conditional probability P_i (-), flammables only

   The probability of weather class, M, and wind direction, φ, occurring simultaneously is given by $P_M \times P_\varphi$.

2. Select a grid cell. The number of people in the grid cell is N_{cell}.

3. Calculate the fraction of deaths, F_d, in the grid cell given the LOC, S, the weather class, M, the wind direction, φ, and ignition event, i. This calculation is elaborated in Section 6.2.5 for toxic substances and Section 6.2.6 for flammable substances. The reference height for the calculation of effects is equal to one metre.

4. Calculate the expected number of deaths in the grid cell, $\Delta N_{S,M,\varphi}$, given the LOC, S, the weather class, M, the wind direction, φ, and ignition event, i.

$$\Delta N_{S,M,\varphi,i} = F_d \; x \; N_{cell}, \qquad (6.3)$$

   The expected number of deaths in the grid cell is not necessarily a whole number.

5. Repeat steps 2 - 4 for all grid cells. Calculate the contribution of all grid cells to the total number of deaths, $N_{S,M,\varphi,i}$, for the LOC, S, weather class, M, and wind direction, φ, and ignition event, i.

$$N_{S,M,\varphi,i} = \sum_{all\ grid\ cells} \Delta N_{S,M,\varphi,i} \qquad (6.4)$$

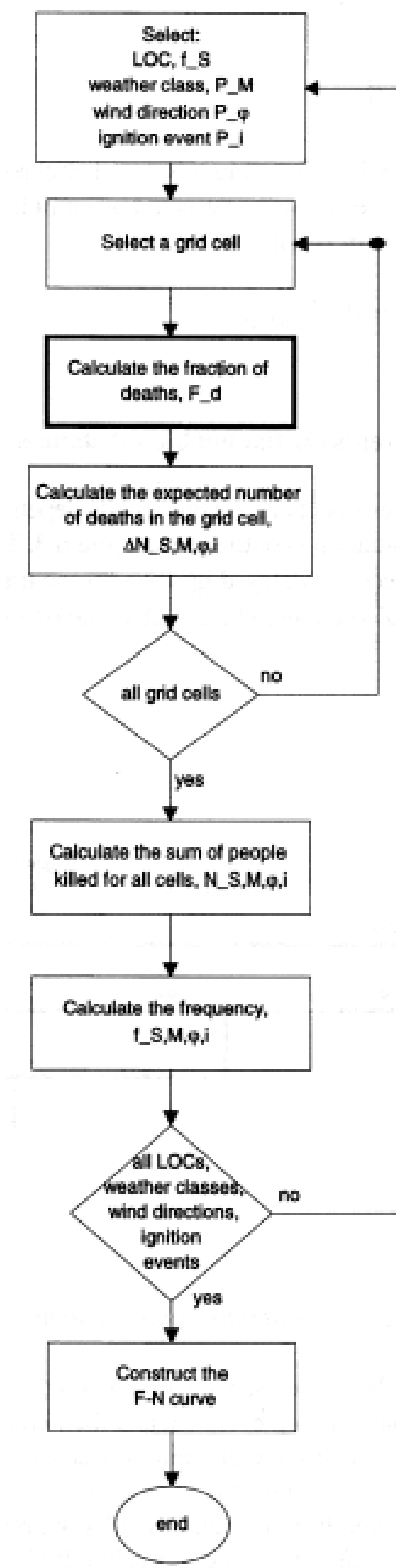

Figure 6.2 Procedure to calculate the Societal Risk.

6. Calculate the frequency, $f_{S,M,\varphi,i}$, of the combined LOC, S, weather class, M, wind direction, φ, and ignition event, i.

$$f_{S,M,\varphi,i} = f_S \times P_M \times P_\varphi \times P_i \qquad (6.5)$$

7. Repeat the calculation steps 1 - 6 for all LOCs, weather classes and wind directions and ignition events. The FN curve is now constructed by cumulating all frequencies $f_{S,M,\varphi,i}$ for which $N_{S,M,\varphi,i}$ is greater than or equal to N:

$$FN = \sum_{S,M,\varphi,i} f_{S,M,\varphi,i} \quad with\ N_{S,M,\varphi,i} \geq N \qquad (6.6)$$

6.2.4 Definition of ignition events for flammable substances

A release of flammable substances results in various events depending on whether there is a direct or delayed ignition. The situation is outlined in Figure 6.. The tree of events shows possible outcomes following direct and delayed ignition for the time steps 0 - ΔT, ΔT - 2ΔT, ... ; ΔT is the time step used in the calculations. The possible outcomes of the event tree are:

- BLEVE
- jet fire and pool fire
- flash fire
- explosion

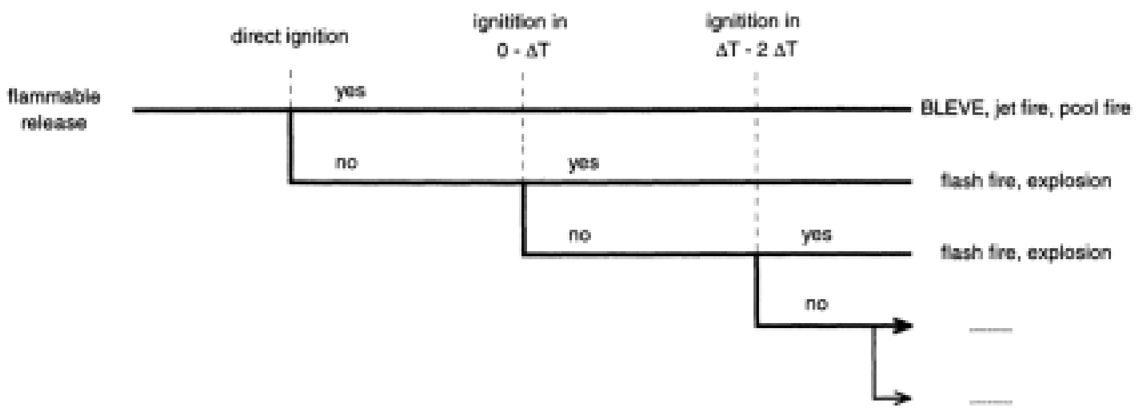

Figure 6.3 Tree of events for the release of flammable substances, using actual ignition sources.

Two different calculation methods can be used, depending on the manner delayed ignition is dealt with, to calculate the various ignition events, i, and their conditional probability, P_i (see Chapter 4). Calculation method A, using actual ignition sources, is described in Section 6.2.4.1. This calculation method is used to determine the Societal Risk and, on special occasions, the Individual Risk. Calculation method B, a free field calculation, is described in Section 6.2.4.2. This calculation method is used to determine the Individual Risk.

6.2.4.1 Calculation with actual ignition sources (method A)

The method using actual ignition sources to calculate the ignition events i and their conditional probability P_i, given LOC, S, weather class, M, and wind direction, φ, is outlined in Figure 6.4.

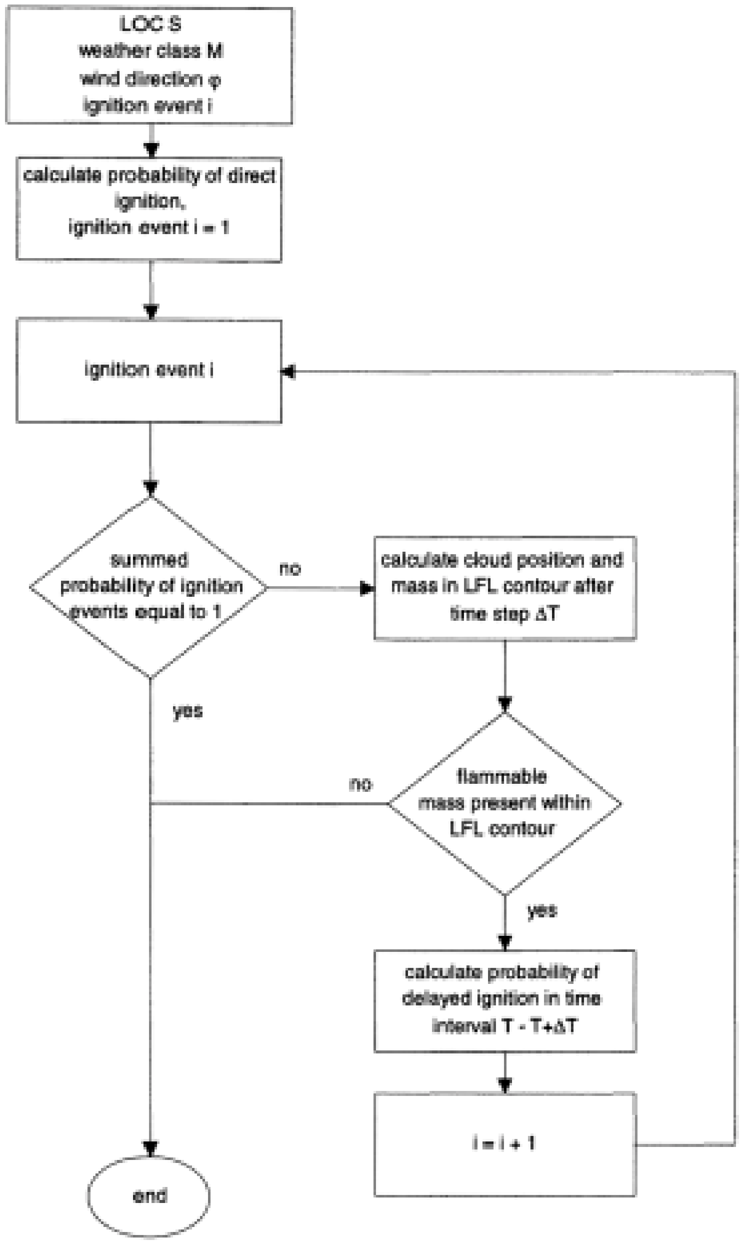

Figure 6.4 Calculation of the ignition events, i, and the conditional probability for a release of flammables using actual ignition sources.

The various steps are illustrated below:

1. Select LOC, S, weather class, M, and wind direction, φ,

2. Calculate the probability of direct ignition. This defines the first ignition event, 'direct ignition'.

3. If the probability of direct ignition is not equal to one, calculate the characteristics of the cloud after time step ΔT.

4. If there is flammable mass within the LFL contour, determine the probability of delayed ignition in time interval ΔT. This probability is equal to (1 – probability of direct ignition) multiplied by the probability of delayed ignition, given the presence of the flammable cloud. This defines the second ignition event, 'delayed ignition in time interval 0 - ΔT'.

5. Calculate the summed probability of all ignition events defined.

6. Repeat steps 3 - 5 as long as the summed probability of all ignition events defined is less than one and as long as there is flammable mass within the LFL contour.

6.2.4.2 Free field calculation (method B)

The free field calculation uses actual ignition sources at the establishment only. If ignition does not occur at the establishment, ignition occurs at maximum cloud extent, being defined as the maximum area of the footprint of the LFL contour (see Chapter 4). The free field method to calculate the ignition events i and their conditional probability P_i, given LOC, S, weather class, M, and wind direction, φ, is outlined in Figure 6.5.

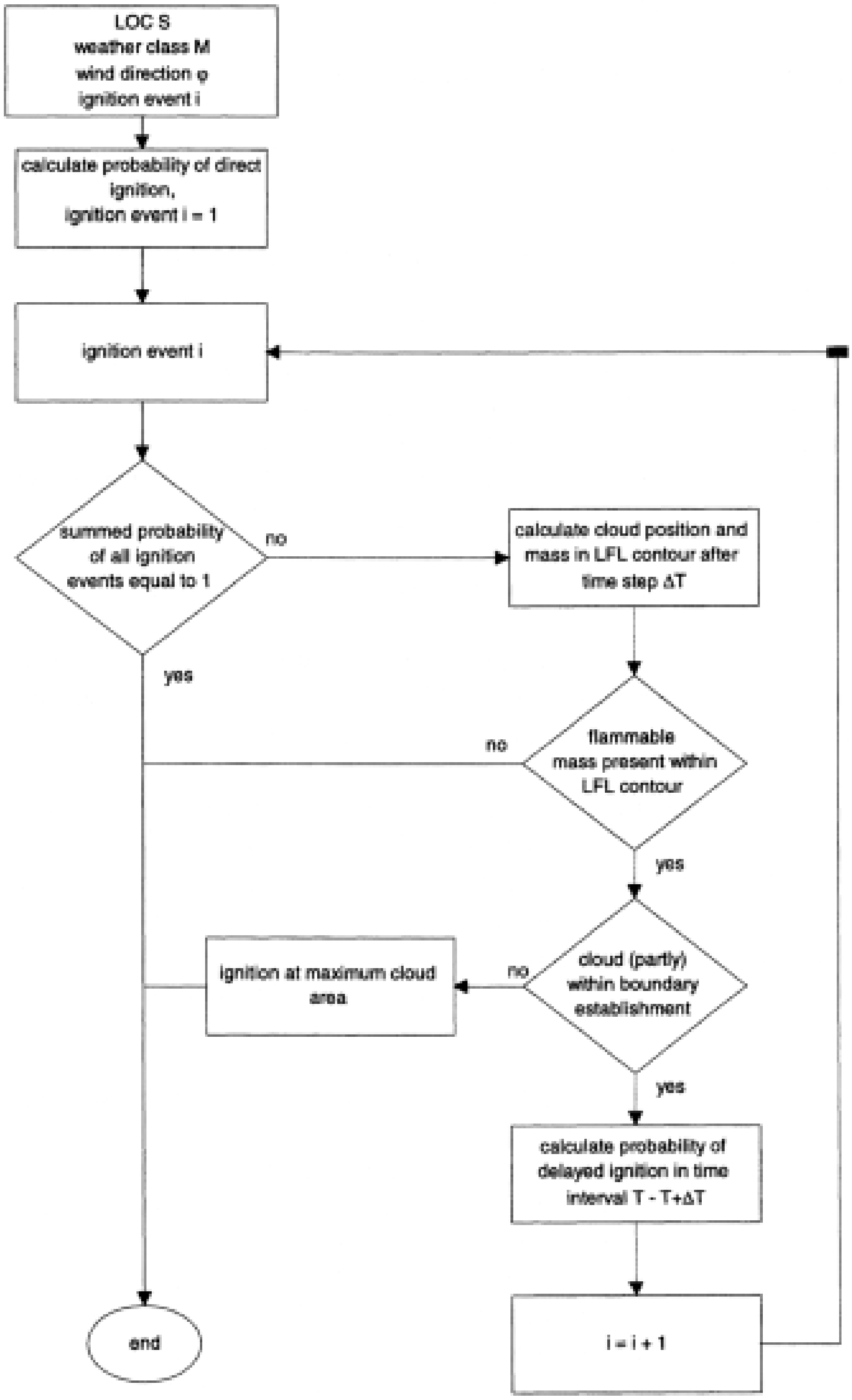

Figure 6.5 Calculation of the ignition events, i, and the conditional probability for a release of flammables using the free field method.

The various steps are illustrated below:

1. Select LOC, S, weather class, M, and wind direction, φ,

2. Calculate the probability of direct ignition. This defines the first ignition event, 'direct ignition'.

3. If the probability of direct ignition is not equal to one, calculate the characteristics of the cloud after a time step ΔT.

4. If there is flammable mass within the LFL-contour, determine the probability of delayed ignition in time interval ΔT, using only the ignition sources at the establishment. This probability is equal to (1 – probability of direct ignition) multiplied by the probability of delayed ignition, given the presence of the flammable cloud. This defines the second ignition event, 'delayed ignition in time interval 0 - ΔT'.

5. Calculate the summed probability of all ignition events defined.

6. Repeat steps 3 - 5 as long as the summed probability of all ignition events is less than one, as long as there is flammable mass within the LFL-contour and as long as the LFL-contour of the cloud covers part of the area of the establishment.

7. If (1) the LFL-contour of the cloud is outside the boundary of the establishment, (2) the summed probability of all ignition events is less than one and (3) there is flammable mass within the LFL-contour, an additional ignition event is defined with probability (1 – summed probability of all ignition events). Ignition takes place at maximum cloud extent, defined as the maximum area of the footprint of the LFL-contour. The position of the cloud and the flammable mass within the cloud will be determined iteratively.

6.2.5 Probability of death, P_d, and fraction of deaths, F_d, for toxic substances

A crucial step in the procedure to determine the Individual Risk and the Societal Risk is the calculation of the probability of death at grid point, P_d, and the fraction of deaths in the grid cell, F_d, given a Loss of Containment event, a weather class and a wind direction (see Figure 6.1 and Figure 6.2). In this section the procedure to calculate these factors is described for a release of toxic substances. It is assumed that the toxic clouds are limited in width and cover only one wind sector. The situation where the cloud covers a large number of wind sectors is described in Section 6.2.6, where the calculation procedure for a release of flammable substances is described.

The method to calculate the probability of death at a grid point, P_d, and the fraction of deaths in a grid cell, F_d, given the LOC, S, the weather class, M, and the wind direction, φ, is outlined in Figure 6.. Essentially, the toxic cloud at the position of the grid point is replaced with an effective cloud having a uniform probability of death. Next, the probability of death at grid point, P_d, is calculated by multiplying the probability of death within the (effective) cloud by the probability that the grid point is located inside the (effective) cloud. The various steps are illustrated below:

1. Calculate the distance, R, between the grid point and the source.

2. Calculate the concentration C(R, t) on the centre line at height h = 1 m for all times, t, following the methods described in Chapter 4.

3. Calculate the probability of death, $P_{cl}(R)$, and the fraction of deaths, $F_{cl}(R)$, on the centre line of the plume at distance R and at the reference height h = 1 m, according to the relationships described in Section 5.2.2.

   The fraction of deaths, $F_{cl}(R)$, is calculated as the sum of the fraction of deaths indoors, $F_{E,in}$, multiplied by the fraction of people indoors, $f_{pop,in}$, and the fraction of deaths outdoors, $F_{E,out}$, multiplied by the fraction of people outdoors, $f_{pop,out}$:

   $$F_{cl} = F_{E,in} \times f_{pop,in} + F_{E,out} \times f_{pop,out} \qquad (6.7)$$

4. The probability of death decreases away from the centre line of the plume. Calculate the probability of death, P(R,y), as a function of the distance to the centre line, y.

5. Calculate the effective width of the cloud, ECW, at distance R.

   The toxic cloud is now replaced at distance R with an effective cloud, a uniform cloud with a constant probability of death equal to the probability of death on the centre line of the toxic cloud. The effective cloud width is determined by the standard that the number of deaths in the toxic cloud is equal to the number of deaths in the effective cloud. The effective cloud width can be calculated with the probability integral. The probability integral, PI (R), is defined as the integral of the probability of death along the axis perpendicular to the centre line of the plume:

   $$PI(R) = \int_{-\infty}^{\infty} P(R,y)\,dy \qquad \text{(m)} \qquad (6.8)$$

   with:
   y distance to the centre line of the plume
   P(R,y) probability of death at location (R,y).

   In a numerical calculation, the boundaries of the integral can be taken as the distance corresponding with 1% lethality.

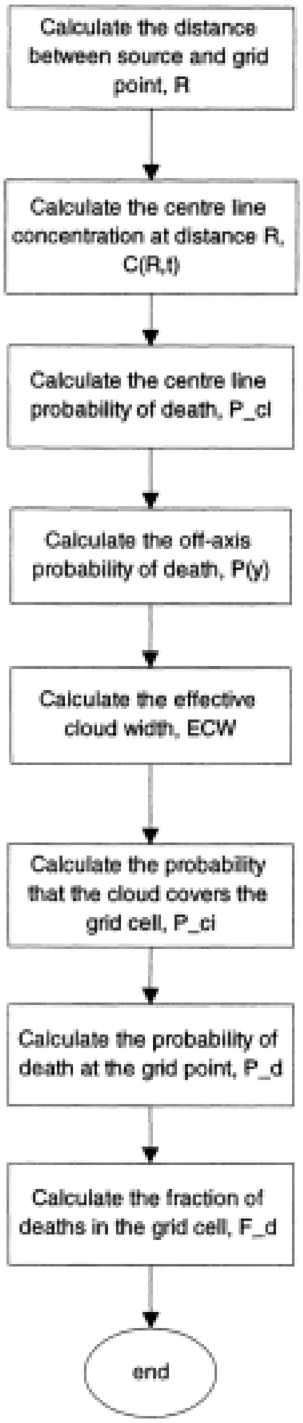

Figure 6.6 Calculation of the probability of death, P_d, and the fraction of deaths at grid point, F_d, for toxic releases.

The effective cloud width, ECW, is then defined as:

$$ECW(R) = \frac{PI(R)}{P_{cl}(R)} \quad \text{(m)} \tag{6.9}$$

6. Calculate the probability, P_{ci}, that the grid point is covered by the effective cloud. In the first approximation, the probability that the grid point is covered by the effective cloud is given by:

$$P_{ci}(R) = \frac{n_{ws} \times ECW(R)}{2 \times \pi \times R} \tag{6.10}$$

   if the grid point is situated in the wind sector and $P_{ci}(R) = 0$ if the grid point is not situated in the wind sector. The parameter n_{ws} is equal to the number of wind sectors.

   The validity of this equation is discussed in Appendix 6.A.

7. Calculate the probability of death at the grid point, P_d, as:

$$P_d \times P_{cl} \times P_{ci} \tag{6.11}$$

8. Calculate the fraction of deaths in the grid cell as:

$$F_d \times F_{cl} \times P_{ci} \tag{6.12}$$

A samplelateculation is given in Appendix 6.B.

6.2.6 Probability of death, P_d, and fraction of deaths, F_d, for flammables

In this section the procedure to calculate the probability of death at a grid point, P_d, and the fraction of deaths in the grid cell, F_d, given a Loss of Containment event, S, a weather class, M, a wind direction, φ, and an ignition event, i, is described for the release of flammable substances.

The impact area is assumed to be large, covering at least several wind sectors. In this way, the jet fire, the pool fire, the flash fire, as well as the explosion, can be situated on the centre line of the wind sector. The condition that the impact area will cover several wind sectors is, in general, valid if the cloud is ignited nearby the source. The situation in which the impact area is small with respect to the boundaries of the wind sector is described in Section 6.2.5, where the calculation procedure for a release of toxic substances is described.

The various steps are outlined in Figure 6.7:

1. Calculate the flame envelope in the event of fire and the contours of 0.3 and 0.1 bar overpressure in the event of a vapour cloud explosion.

2. Calculate the location of the grid point relative to the flame envelopes, overpressure contours and the source of heat radiation.

3. Calculate the heat radiation, Q(x,y,t), at the grid point if the grid point is outside the flame envelope in the event of BLEVE, and jet and pool fires. The calculation method is described in the ‘Yellow Book’.

4. Calculate the probability of death at the grid point, P_d, following the methods described in Chapter 5.

5. Calculate the fraction of deaths in the grid cell, F_d, following the methods described in Chapter 5. The fraction of deaths, F_d, is calculated as the sum of the fraction of deaths indoors, $F_{E,in}$, multiplied by the fraction of people indoors, $f_{pop,in}$, and the fraction of deaths outdoors, $F_{E,out}$, multiplied by the fraction of people outdoors, $f_{pop,out}$:

$$F_d = F_{E,in} \times f_{pop,in} + F_{E,out} \times f_{pop,out} \tag{6.13}$$

Note:

1. In the event of a flash fire, the probability of death changes abruptly from one to zero. To have a more gradual change in the Individual Risk and Societal Risk, it is recommended to set P_d and F_d equal to the fraction of the grid cell covered by the flash fire flame envelope if the grid cell is partially located in the flame envelope. The same procedure can be applied to the contours of 0.3 and 0.1 bar overpressure in the event of a vapour cloud explosion.

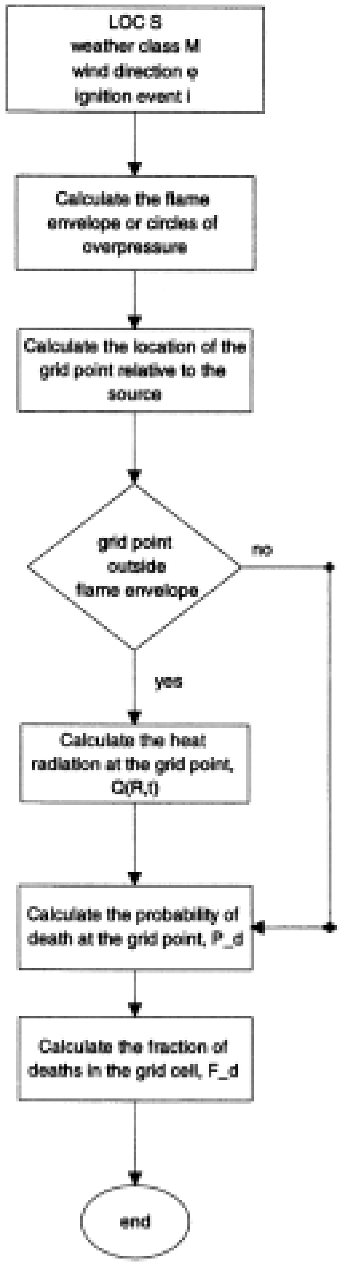

Figure 6.7 Calculation of the probability of death, P_d, and the fraction of deaths at a grid point, F_d, for a release of flammables.

6.3 Presentation of the results

The results of a QRA are the Individual Risk and the Societal Risk, both of which should be presented clearly.

- The Individual Risk must be presented as contour lines on a normal topographic map. The Individual Risk contours with frequencies of 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} and 10^{-8} per year must be displayed, if in existence. The scale of the topographic map should be appropriate to displaying the risk contours. It is advised to use one of the standard scales, i.e. 1 : 10,000, 1 : 25,000, 1: 50,000 or 1: 250,000. An illustration is shown in Figure 6.7.

- The Societal Risk must be plotted as an FN-curve.
  - The x-axis of the FN-curve represents the number of deaths, N. The number of deaths is placed on a logarithmic scale and the minimum value should be displayed as 1.
  - The y-axis of the FN-curve represents the cumulative frequency of the accidents, with the number of deaths equal to N or more. The cumulative frequency is placed on a logarithmic scale and the minimum value should be displayed as 10^{-9} y^{-1}.

  An illustration is shown in Figur.

As well as the presentation of the Individual Risk and the Societal Risk, other results can be presented, which will evaluate and judge the risks. Useful presentations can be figures of the probability of death on the centre line, P_{cl}, as a function of distance, x, for the decisive LOC's.

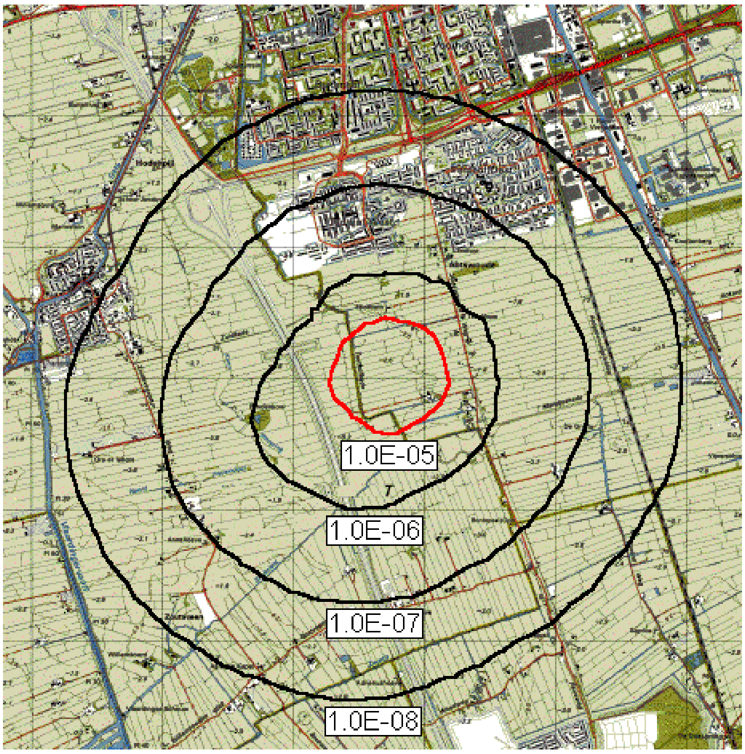

Figure 6.8 Presentation of the Individual Risk contours. Shown are the Individual Risk contours 10^{-5}, 10^{-6}, 10^{-7} and 10^{-8} y^{-1} of a fictive plant .

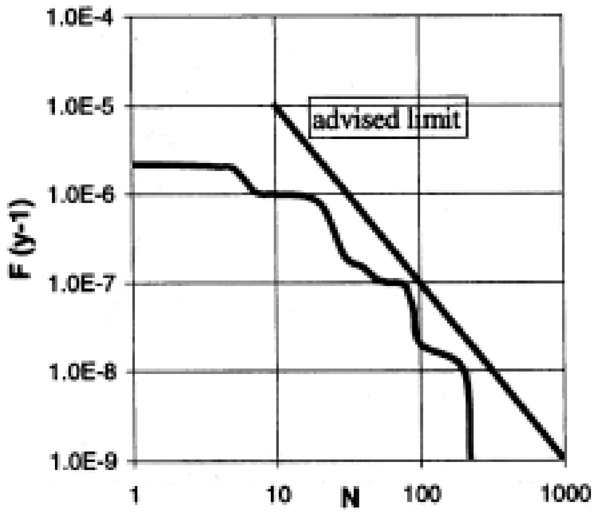

Figure 6.8 Presentation of the societal risk curve. Indicated are the FN curve of a fictive plant and the recommended limit for establishments ($F < 10^{-3} \times N^{-2}$ y^{-1} for $N \geq 10$).

Appendix 6.A Probability that the grid point is covered by the cloud, P_{ci}

In the calculation of the probability of death, P_d, for toxic clouds we use the probability, P_{ci}, that the grid point is covered by the (effective) cloud. In the first approximation P_{ci} is given by:

$$P_{ci}(R)=\frac{n_{ws}\times ECW(R)}{2\times\pi\times R} \tag{6.A.1}$$

if the grid point is situated in the wind sector and $P_{ci}(R) = 0$ if the grid point is situated outside the wind sector.

The validity of this approximation is discussed in this appendix.

The origin of this equation can easily be shown in Figure 6.A.1, where the following is valid for grid point A:

$$P_{ci}=\frac{2\times\mu}{\theta}=\frac{2\times\pi\times\left(ECW(R)/(2\times\pi\times R)\right)}{2\times\pi/n_{ws}}=\frac{n_{ws}\times ECW(R)}{2\times\pi\times R} \tag{6.A.2}$$

The equation is only valid for grid points in the centre of the wind sector and for small cloud width. However, if the probability of the wind direction, P_φ, does not vary much between adjacent wind sectors, the equation is also applicable for grid points situated near the boundary of a wind sector and for large cloud widths.

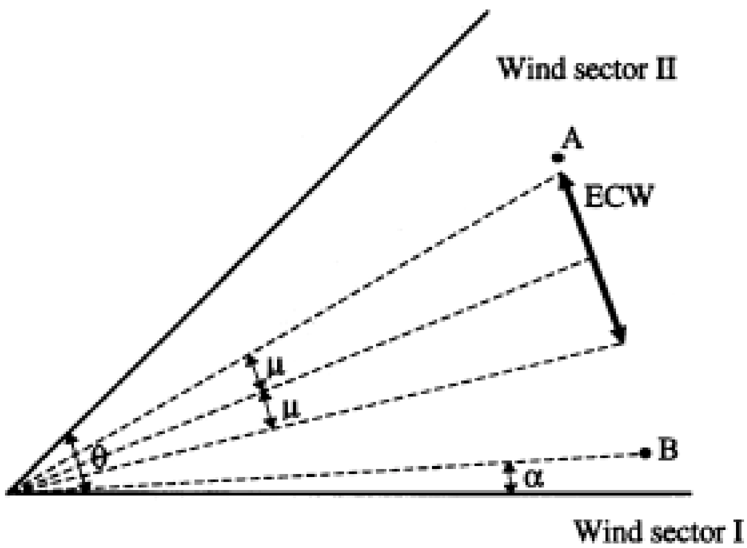

Figure 6.A.1 Calculation of the probability, P_{ci}, that the grid point is covered by the cloud.

If the grid point is situated near the boundary of a wind sector, a combination of two wind sectors has to be used. For example, in Figure 6.A.1 for grid point B, where $\alpha < \mu$, the contribution of wind sector II is proportional to:

$$P_{ci,II}(R) = \frac{n_{ws} \times ECW(R)}{2 \times \pi \times R} \frac{\alpha + \mu}{2 \times \mu} \tag{6.A.3}$$

and the contribution of wind sector I is proportional to:

$$P_{ci,I}(R) = \frac{n_{ws} \times ECW(R)}{2 \times \pi \times R} \frac{\mu - \alpha}{2 \times \mu} \tag{6.A.4}$$

If the conditional probability P_φ does not differ much between the two wind sectors, i.e. $P_I \approx P_{II}$, the sum of the contributions of the two wind sectors is equal to:

$$\begin{aligned} \Delta IR_{S,M,I} + \Delta IR_{S,M,II} &= f_S \times P_M \times P_{cl} \times (P_I \times P_{ci,I} + P_{II} \times P_{ci,II}) \\ &= f_S \times P_M \times P_{cl} \times P_I \times (P_{ci,I} + P_{ci,II}) \\ &= f_S \times P_M \times P_{cl} \times P_I \times P_{ci} \end{aligned} \tag{6.A.5}$$

Hence, the approximation is also valid near the boundary of the wind sector, provided that the conditional probability, P_φ , does not differ much between two wind sectors.

If the effective cloud width, ECW, is larger than the width of the secto $\frac{2 \times \pi \times R}{n_{ws}}$, the probability that the grid point is covered by the cloud, P_{ci}, would be larger than 1. This is, of course, not a correct value for a probability. However, it can be shown that the formula is still valid if the conditional probability, P_φ, does not differ much between adjacent wind sectors. In Figure 6.A.2, a simplified case is shown, in which the contributions of the wind sectors I, II and III to the risk increment are calculated.

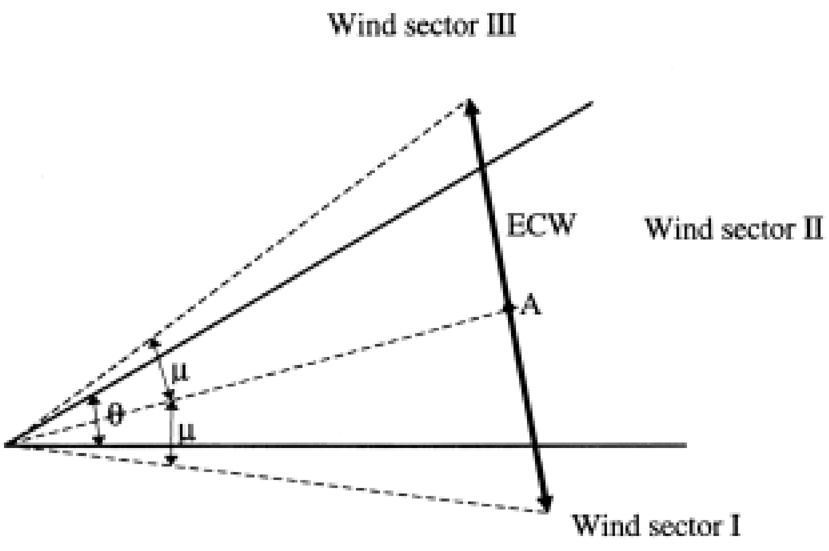

Figure 6.A.2 Calculation of the probability, P_{ci}, that the grid point is covered by the cloud for large values of ECW.

The contribution of the wind sectors I and III to the Individual Risk at grid point A is proportional to:

$$P_{ci,I}(R) = P_{ci,III}(R) = \frac{\mu - 0.5\times\theta}{\theta}, \text{ (AI.1)}$$

and the contribution of wind sector II is proportional to:

$P_{ci,II}\ (R) = 1$

If the conditional probability P_φ does not differ much between the two wind sectors, i.e. $P_I \approx P_{II} \approx P_{III}$, the sum of the contributions of the three wind sectors is equal to:

$$\begin{aligned}\Delta IR_{S,M,I} + \Delta IR_{S,M,II} + \Delta IR_{S,M,III} &= f_S \times P_M \times P_{cl} \times (P_I \times P_{ci,I} + P_{II} \times P_{ci,II} + P_{III} \times P_{ci,III}) \\ &= f_S \times P_M \times P_{cl} \times P_I \times (P_{ci,I} + P_{ci,II} + P_{ci,III}) \\ &= f_S \times P_M \times P_{cl} \times P_I \times P_{ci}\end{aligned}$$

The approximation is also shown to be valid if the effective cloud width, ECW, is larger than the width of the sector, $\frac{2\times\pi\times R}{n_{ws}}$, provided that the conditional probability, P_φ, does not differ much between adjacent wind sectors.

It should be noted that the same conclusion holds for the Societal Risk calculation if the population distribution does not vary much with the wind direction.

If either the probability of the wind direction, P_φ, or the population distribution does vary considerably between adjacent wind sectors, the contributions of clouds in adjacent wind sectors have to be taken into account explicitly according to the method outlined here.

Appendix 6.B Sample calculation of the Individual Risk at a grid point

A pipe rupture at the origin results in a continuous release of 100 kg/s CO. The frequency of the pipe rupture is 5×10^{-7} y^{-1}. The release takes place at a height of 1 m and $z_0 = 0.1$ m. Calculate the contribution of this LOC to the Individual Risk at the grid point (200, 300) using the weather data of the Rotterdam weather station.

The calculation is carried out for the weather class D 5.0 m s^{-1} only.

1. The LOC selected is a pipe rupture leading to a continuous release of 100 kg/s CO. The frequency of the LOC 'pipe rupture' is $f_s = 5 \times 10^{-7}$ y^{-1}.

2. The weather class selected is D 5.0 m s^{-1}.

3. The relevant wind sector is the sector 196° - 225°. The probability of weather class D 5.0 m s^{-1} and this wind sector occurring is 0.0376 during daytime and 0.0362 during night time (see Appendix 4.C). Daytime and night-time correspond with fractions 0.44 and 0.56 of the day, respectively. The probability of the weather class, $P_M \times P_\varphi$, is therefore $0.44 \times 0.0376 + 0.56 \times 0.0362 = 0.0368$.

4. Calculation of the probability of death, P_d, at the point (100, 200).

   4.1 The distance between the grid point (200, 300) and the source at (0,0) is 361 m.

   4.2 The concentration on the centre axis is calculated using the basic expressions for the Gaussian plume model for a continuous release.

$$C(x,y,z) = \frac{q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(h-z)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(h+z)^2}{2\sigma_z^2}\right)\right] \qquad (6.B.1)$$

   The calculation is given below, resulting in:

   C (x = 361 m, y = 0 m, z = 1 m) = 21.3 g m^{-3}

   4.3 The toxic constants of CO are a = –7.4, b = 1 and n = 1 if the concentration, C, is given in mg m^{-3} and the exposure time, t, in minutes. Using the concentration on the centre axis, C = 21,300 mg m^{-3}, and the maximum exposure time, t = 30 min, the probit value, Pr = 5.97. The probability of death on the centre line of the plume, P_{cl} = 0.835, conforms to Table 5.1.

   4.4 The concentration outside the plume axis is given by:

$$C(x=361, y, z=1) = 21300 \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \quad \text{mg m}^{-3} \qquad (6.B.2)$$

The probability of death, P(y), is derived from the concentration, C(x = 361 m, y, z = 1 m), the exposure time, t = 30 min, and the probit function of CO.

5. The PI is given by:

$$PI = \int_{-\infty}^{\infty} P(y)\,dy \tag{6.B.3}$$

Figure 6.B.1 shows the function P(y) and the effective cloud width. In the calculation the boundaries of the integral are replaced by the distance corresponding to 1% lethality. A straightforward calculation gives PI = 72 m. The effective cloud width, ECW, is then calculated as:

$$ECW = \frac{PI}{P_{cl}} = \frac{72\,\text{m}}{0.835} = 86.2\,\text{m}$$

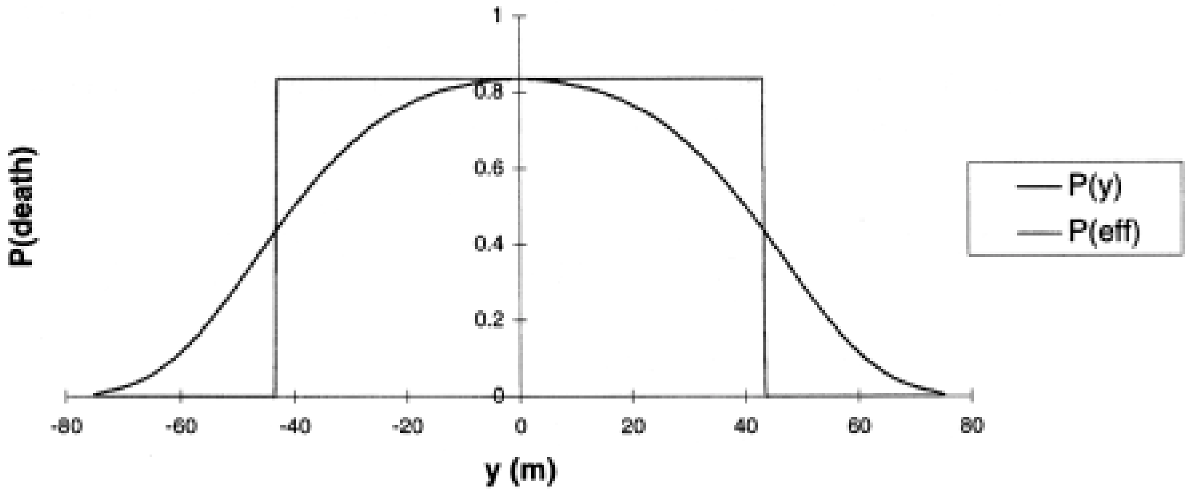

Figure 6.B.1 The probability of death, P(y), as a function of the cross-wind distance, y, and the effective cloud.

5.1 The probability that the grid point (200, 300) is covered by the plume, P_{ci}, is given by:

$$P_{ci} = \frac{n_{ws} \times ECW}{2 \times \pi \times R} = \frac{12 \times 86.2\,\text{m}}{2 \times \pi \times 361\,\text{m}} = 0.456$$

5.2 The probability of death at the grid point, P_d, is equal to:

$P_d = P_{cl} \times P_{ci} = 0.381$

6. The contribution, $\Delta IR_{pipe\ rupture,M,\varphi}$, of the LOC ‘pipe rupture’, with weather class D 5.0 m s^{-1} and wind direction in sector of 196° - 225°, to the Individual Risk at grid point (200, 300) is therefore:

$$\Delta IR_{pipe\ rupture,M,\varphi} = f_{pipe\ rupture}, \times P_M \times P_\varphi \times P_d = 7.0\ \ 10^{-9}\ y^{-1}$$

7. The total contribution of the LOC ‘pipe rupture’ to the Individual Risk, $\Delta IR_{pipe\ rupture}$, at grid point (200, 300) is the sum taken over all (12) wind directions and all (6) weather classes.

$$\Delta IR_{pipe\ rupture} = \sum_M \sum_\varphi \Delta IR_{pipe\ rupture,M,\varphi} \quad (6.B.4)$$

The contribution of the other wind directions is zero. The contribution of the other weather classes can be similarly calculated.

Calculation of the concentration for neutral dispersion

The concentration on the centre axis is calculated using the basic expressions for the Gaussian plume model for a continous release (equations 4.51, 4.53a and 4.57a in [CPR14E]) assuming total reflection to the ground surface.

$$C(x,y,z) = \frac{q}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(h-z)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(h+z)^2}{2\sigma_z^2}\right)\right]$$

The parameters are:

- x the co-ordinate along the plume axis, equal to 361 m
- y the co-ordinate perpendicular to the plume axis. As the concentration is calculated on the plume axis, y = 0 m
- z the height where the concentration is calculated, equal to 1 m
- q the release strength, equal to 100 kg s^{-1}
- h the height of the release, equal to 1 m
- u the wind velocity. As the height of the release is less than 10 m, the wind velocity of the plume is equal to the wind velocity at 10 m, i.e. 5 m s^{-1}

The dispersion coefficients, σ_y en σ_z , are calculated using u_*, yielding the following results:

1/L	= 0 m^{-1}	(Table 4.1, stability: neutral)
u_*	= 0.434 m s^{-1}	(Equation 4.31, using z = 10 m, z_0 = 0.1 m and u_a = 5 m s^{-1})
h_i	= 500 m	(Table 4.7, using 0.2 x u_* / f ≈ 770 m)
h	= 1 m	(the height of the release)
σ_v	= 0.823 m s^{-1}	(Equation 4.49)
σ_y (1h)	= 41.2 m	(Equation 4.54, averaging time 1 h, using t_i = 300 s, u_a = 5 m s^{-1} and x = 361 m)
σ_y (10m)	= 28.8 m	(Equation 4.55, using averaging time 10 min. The value is larger than the minimum value given in Equation 4.56)
σ_z	= 10.3 m	(Equation 4.58a)

Substituting the parameter values results in: C (x = 361 m, y = 0 m, z = 1 m) = 21.3 g m^{-3}.

Appendix 6.C Commentary

The rule that calculations may terminate at 1% lethality is copied from [KO 20-2].

The presentation of the Individual Risk and Societal Risk is taken from [BRZO]. The minimum value displayed in the FN-curve used to be 10^{-8} y^{-1} [BRZO] but has now changed to 10^{-9} y^{-1}.

7. QUANTITATIVE ENVIRONMENTAL RISK ANALYSIS

A Quantitative Risk Analysis (QRA) is used to demonstrate the risks caused by an activity involving dangerous substances. The risks calculated in a QRA refer to the external safety, i.e. the probability of persons off-site dying from exposure. However, an accident with hazardous substances may also result in damage to the environment. Examples of environmental damage are:

- Contamination of groundwater by oil spills. As a result, large areas may become unfit for drinking-water preparation.
- Contamination of surface waters by spills of toxic substances. As a result, life may not be supported in a watercourse for a prolonged period of time.
- Contamination of surface soil by deposition of harmful substances like dioxins and asbestos. As a result, large areas may become unfit for agriculture and human habitation, and clean-up may be needed.

A quantitative environmental risk analysis aims at quantifying the risks of environmental impacts caused by accidental releases.

An accidental release can lead to impacts in three environmental compartments: air, soil (including groundwater) and surface water. Past accidents with severe environmental consequences have mostly been related to surface-water pollution. The emphasis of environmental risk quantification has therefore been in this area. A model to quantify the environmental risks has, to date, only been developed for the surface water compartment. This model, PROTEUS, is an aggregation of two models, VERIS and RISAM, which up to now were used in the Netherlands to evaluate the risks to surface waters.

PROTEUS is a model to calculate the risk to surface waters and sewage treatment plants caused by an activity with substances which are dangerous to the environment. The risk of an activity consists of the frequency and the consequences of the spill.

- The frequency of a spill is calculated using default failure frequencies, modified by factors for the technical design of the installation, operational factors (e.g. maintenance of an installation and working procedures) and management factors. Site-specific information is, in this way, incorporated into the analysis.
- The consequences of a spill depend on the amount of substance spilled and the location-specific properties of the surface water. The amount of substance spilled depends on the availability of preventive and mitigating measures.

The results of PROTEUS are presented as a frequency–damage curve similar to the FN-curve in the QRA. The x-axis represents a measure of environmental damage and the y-axis represents the cumulative frequency of this environmental damage. Three possible measures of damage can be chosen:

- the amount of substance spilled (in kg).
- the area of the surface water affected by the spill (in m^2 or m^3).
- an environmental damage index.

PROTEUS is from end 1998 available as a β-version [AVIV98].

8. THE USE OF NEW MODELS IN A QRA

A Quantitative Risk Analysis (QRA) is used to determine the risk caused by the use, handling, transport and storage of dangerous substances. The results of the QRA are, for example, used to assess the acceptability of the risk in relation to the benefits of the activity, to evaluate new developments on- and off-site, to estimate the benefit of risk-reducing countermeasures and to determine zoning distances around an activity for land-use planning.

A QRA is intended to give the best estimate of the actual risk level caused by the activity; a QRA calculation can therefore lead either to an underestimation or an overestimation of the actual risk level. Since a QRA is intended to give the best estimate, the models used in the QRA represent the current state of technology and are regularly updated as scientific knowledge increases. New developments in hardware allow the use of more complex models. The application of an improved model in a QRA results in either an increase or a decrease in the calculated risk, even if the actual risk is not changed. This is contrary to a more conservative approach, in which the calculated risk is assumed to be an overestimation of the actual risk; the application of an improved model here should result in a reduced overestimation.

The use of continuously improving models in QRAs may lead to problems in the decision-making process. Examples are:

- Zoning distances based on the location of the Individual Risk contours are set for a number of activities, e.g. transport pipelines and LPG filling stations. The use of an improved model will result in changes in the location of the Individual Risk contours and the zoning distances may appear to be no longer correct.
- If a new QRA is made to determine the risks caused by an activity, the use of new models can lead to changes in the calculated risk. Therefore the risk caused by the activity seems to have changed, although the activity itself and the actual risk have not.
- Countermeasures can be taken to reduce the risk. A new QRA is made to determine the effect of the countermeasures and to quantify the risk reduction achieved. However, the effect of the countermeasures and the risk reduction achieved can be obscured by changes in the calculated risk due to the use of new models in the QRA. The result of the new QRA may even show an increase in the risk calculated despite applying countermeasures.

Recognition of the problems indicated above may lead to the point of view that the models used in a QRA should be kept fixed to keep in line with previous results and with the decisions based on these results. However, scientific progress has led to improved estimations of the actual risk. Consequently, the gap between the best estimate of the risk, as calculated with the newest models, and the unchanging risk levels, as calculated with the fixed models, increases with time. Fixing the models can thus lead to other problems:

- New models may indicate that larger zoning distances are required for some activities. If the zoning distances are kept fixed, a situation is created that is considered to be unsafe.
- New models may indicate that shorter zoning distances are allowed for some activities. If the zoning distances are kept fixed, an excessively large area is taken up by the activity no longer demanded by the risk.

It has therefore been decided to construct a QRA using the current state of technology and the best models available for this purpose. This is in line with the approach in this guidebook: although a number of calculation methods are advised, more suitable models can be used when available. The adequacy of the QRA and the models used is to be decided by the competent authorities. Therefore, the user should demonstrate adequate scientific performance in applying new models to the competent authorities. The scientific performance of the models should be demonstrated using the results of validation exercises, model intercomparison studies and/or publications.

If the QRA is made as an update of an existing QRA to incorporate developments on- and off-site, it is strongly advised to compare the results of the new and existing QRA to facilitate decision-making processes. The comparison should indicate both the effect of the use of the new models and of the developments on-site and off-site on the calculated risk.

9. UNCERTAINTY IN A QRA

9.1 Introduction

A Quantitative Risk Assessment (QRA) is used to determine the risk caused by an activity involving dangerous substances. The result of a QRA is the risk around the location of the activity. Risk is usually presented as a single value, for instance, the frequency of death due to an accident in the nearby establishment on location (x, y) is 2.3×10^{-7} per year. However, QRA results are calculated with various models having a limited accuracy and for that reason the results of the QRA calculation have an uncertainty associated with them.

In this chapter, various sources of qualitative uncertainty are discussed, followed by a short outline on the implications of the evaluation of the QRA results. This chapter is not intended to give a complete description of all possible sources of uncertainties, but merely to discuss various types of uncertainty in the QRA. A more elaborate discussion on uncertainties can be found in the references and references therein, for example [CPR12E, IAEA89, SRPI96].

The term ‘uncertainty’ is used in this chapter as a measure of distinction between the model calculation and the actual situation.

9.2 Sources of uncertainty

Various sources of uncertainty are found in a QRA calculation. The sources of uncertainty are classified here according to the various levels of QRA calculations: starting points, models, parameter values and the use of the model.

9.2.1 Starting points

Before a QRA calculation is started, choices have to be made with regard to the starting points. For instance, a conservative approach requires a different type of model and a different set of parameter values than a best-estimate calculation. Another illustrative example is given as the following question:

Does the QRA indicate the actual individual risk around an activity, or does the QRA indicate an artificial individual risk that is independent of the surroundings of the activity?

The consequences of such a choice can easily been seen for releases of flammable substances. If the QRA is meant to estimate the actual risk, the probability that the flammable cloud will ignite should be calculated using the location of ignition sources around the activity. On the other hand, if the QRA is meant to calculate an individual risk independent of the surroundings of the activity, the ignition sources around the activity should be ignored and agreements will have to be made on the ignition of flammable clouds.

This guideline has established a number of starting points and in doing so minimises the associated uncertainties. However, differences in starting points may hamper the comparison of new QRAs with those made previously and the comparison of QRAs made for establishments with those made for transport activities.

9.2.2 Models

When the starting points of the QRA are defined, appropriate models have to be used. Uncertainties arise from various sources:

- A number of potentially important processes may be ignored in the models. Examples are tank-roof collapse, atmospheric deposition processes and chemical reactions in the dispersing cloud.
- The models are not valid for the specific local situation. For instance, the dispersion models used are only valid for a flat terrain in the absence of large obstacles, whereas numerous obstacles can be present in and around industrial sites.
- Processes are often simplified in models. For instance, sometimes a uniform wind speed is used, ignoring the variation in wind speed with height.
- Natural variability is ignored. As an example, all humans are assumed to react similarly to an exposure to toxic substances. However, elderly people are probably more vulnerable and thus are at greater risk.
- Models are sometimes used outside the range of applicability. For instance, dispersion models that are validated for neutral gas dispersion are sometimes used to calculate the dispersion of heavy or light gases. Dispersion models are occasionally also used at distances outside the validity range of the model.
- The computer code contains numerical approximations. If the numerical step in space and time is too large, errors are introduced. Also coding errors can be present in the source code of the computer program.

It should be noted that the models for use in the QRA are not strictly established. Different models, varying in complexity and accuracy, can be used in a QRA calculation,. The results of the QRA can depend strongly on the models used (see, for example, [TNO98c]). As a result, the selection of the models in the QRA can determine the assessment of the acceptability of the activity, a problem already touched on in Chapter 8 describing the use of new developments in scientific knowledge.

9.2.3 Parameter values

Before the model can be used, input parameter values are collected from either the literature or experiments. Sources of uncertainty in parameter values are:

- Parameter values are extrapolations of measured data. Toxicity parameters are often derived from animal toxicity data that are measured at a different dose level. Extrapolation occurs from animal to human toxicity and from the doses applied in the experiment to the doses relevant for QRA calculations. Physical data, like the flash fraction, are derived from small-scale experiments and need to be extrapolated to large-scale installations.
- Generic data sets are used in the absence of location specific data. For example, often generic data are used for parameters like the roughness of a pipe wall and the failure frequency of a pipeline, since specific data are either not available or too difficult to obtain.
- The data to derive parameter values may be sparse. For instance, failure frequencies of storage tanks are derived from historical data sets. Since accidents are rare, failure frequencies of installations have large uncertainties. Furthermore, databases describe the historical failure rate and these data are possibly no longer valid for present-day installations.

9.2.4 Use of the model

Finally, the models are all used in the QRA. However, different users may have different results using the same model for the same installation, for example:

- The user may misinterpret the model input and output due to inexperience.
- The user can make calculation errors, errors in manual copying of results and in the reporting of the results.
- The user may reduce the calculation time by reducing the number of calculations, e.g. by selecting only a limited number of installations.

9.3 Quantification of uncertainties

To determine the magnitude of some sources of uncertainty and the consequences to the results of the QRA, various tools are available. For example, statistical analysis of historical data gives information on the uncertainty in the failure frequencies derived. The consequences of parameter uncertainty to the model outcome can be determined with the use of sensitivity and uncertainty analysis.

The uncertainty in models can partly be established by model validation studies. In these studies, model predictions are compared with experimental data sets. Alternatively, QRA-type models can be compared to more complex models in model intercomparison studies.

Uncertainties in the results of a QRA are not considered in the decision-making process since the criteria for the evaluation of the acceptability of risk are expressed as single numbers, e.g. at location (x,y) the frequency of dying due to an accident must be less than 1×10^{-6} yr^{-1}. The results of a QRA calculation are therefore also single numbers, which may either overestimate or underestimate the actual risk level due to uncertainties. However, the risk calculated should be a best estimate of the actual risk level and the reliability of the risk calculation should be secured as much as possible by the use of accurate calculation methods.

10. REFERENCES

[AEC75] US Atomic Energy Commission. Reactor safety study - an assessment of accident risks in the U.S. Commercial Nuclear Power Plants; WASH-1400, Appendix III Failure data (and references therein), 1975.

[AM94] AMINAL Dienst Gevaarlijke Stoffen en Risicobeheer. Handboek kanscijfers ten behoeve van het opstellen van een veiligheidsrapport. Brussels: AMINAL, 1994.

[AVIV98] AVIV, RIZA, RIVM, VROM. PROTEUS V1.00. Enschede: AVIV, 1998.

[BR97] Bridgis. Population data for the Netherlands in the year 1996. Druten: Bridgis, 1997.

[BRZO] Besluit risico's zware ongevallen (besluit van 15 september 1988, Stb. 432; laatstelijk gewijzigd bij besluit van 20 juni 1994, Stb. 463). The Hague: SDU, 1988/1994.

[Bu75] Bush S.H. Pressure Vessel Reliability. Trans. of AMSE - Journal of Pressure Vessel Technology, 1975.

[Ch88] Chambers science and technology dictionary. Edingburgh: W & R Chambers Ltd and Cambridge University Press, 1988

[COVO81] COVO Commission. Risk analysis of six potentially hazardous industrial objects in the Rijnmond area, a pilot study. A report to the Rijnmond public authority. Schiedam: Central Environmental Control Agency Rijnmond, 1981.

[CPR12E] Committee for the Prevention of Disasters. Methods for determining and processing probabilities ('Red Book'), Second edition. The Hague: SDU, 1997.

[CPR14] Committee for the Prevention of Disasters. Methoden voor het berekenen van fysische effecten. Voorburg: Ministry of Social Affairs and Employment, 1988[2].

[CPR14E] Committee for the Prevention of Disasters. Methods for the calculation of physical effects (the 'Yellow Book'). The Hague: SDU, 1997[3].

[CPR15] Ministry of Housing, Spatial Planning and the Environment. Risico-analyse methodiek CPR-15 bedrijven. The Hague: Ministry of Housing, Spatial Planning and the Environment, 1997.

[CPR16] Committee for the Prevention of Disasters. Methods for the calculation of damage (the 'Green Book'). Voorburg: Ministry of Social Affairs and Employment, 1990[1]

[DIPPR] Daubert T.E. and Danner R.P. (eds.). DIPPR. Physical and Thermodynamic Properties of Pure Chemicals: Data Compilation. New York: Hemisphere Publishing Corp., 1992.

[DNV96] DNV Technica. SAFETI 3.4 Theory Manual. London: DNV Technica, 1996.

[DNV98] DNV Technica. PHAST 5.2. London: DNV Technica, 1998.

[EU88] Richtlijn van de Raad van 7 juni 1988 betreffende de onderlinge aanpassing van de wettelijke en bestuursrechterlijke bepalingen van de Lid-Staten inzake de indeling, de verpakking en het kenmerken van gevaarlijke preparaten (88/379/EEG). Luxembourg: Office for official publications of the EC, 1988.

[EU96] Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances. Luxembourg: Office for official publications of the EC, 1996.

[EU98] Commission Decision of ___ 1998 on harmonized criteria for dispensations according to article 9 of Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances. Luxembourg: Draft 20.3.1998.

[Gi97] Gilham S., Deaves D.M., Hoxey R.P., Boon C.R. and Mercer A. Gas build-up within a single building volume - comparison of measurements with both CFD and simple zone modelling. Journal of Hazardous Materials 53: 93-114, 1997.

[Hu92] Hurst N.W., Hankin R.K.S., Wilkinson J.A., Nussey C., Williams J.C. Failure rate and incident databases for major hazards. Published in the Proceedings of the 7th International Symposium on Loss Prevention and Safety Promotion in the Process Industry, Taormina, Italy 4 - 8 may 1992. Rome: SRP Partners, 1992.

[IAEA89] International Atomic Energy Agency. Evaluating the reliability of predictions made using environmental transfer models. Vienna: IAEA, 1989.

[IPO] IPO A73. Handleiding voor het opstellen en beoordelen van een extern veiligheidsrapport. IPO Project A73. The Hague: IPO, 1994.
Committee for the Prevention of Disasters, Risk Evaluation. Publication RE-95-1; Tekstwijzigingen op de IPO A73. The Hague: Ministry of Housing, Spatial Planning and the Environment, 1996.

[IPORBM] AVIV. IPO RisicoBerekeningsMethodiek. Enschede: AVIV, 1997.

[Ja71] Jacobs R.M. Minimizing hazards in design. Quality Progress, 1971.

[KNMI72] KNMI (Royal Dutch Meteorological Institute). Climatological data of Netherlands stations. No. 8. Frequency tables of atmospheric stability. De Bilt: KNMI, 1972.

[KNMI92] KNMI (Royal Dutch Meteorological Institute). Klimatologische gegevens van Nederlandse stations ; normalen en extreme waarden van 15 hoofdstations voor het tijdvak 1961-1990. De Bilt: KNMI, 1992.

[KO 9] Knelpuntenoverleg EVR. Aanwijzingssysteem per inrichtingsonderdeel. KO 9. The Hague: Ministry of Housing, Spatial Planning and the Environment , 1989.

[KO 12] Knelpuntenoverleg EVR. Laad en loshandelingen. KO 12. The Hague: Ministry of Housing, Spatial Planning and the Environment , 1989.
Knelpuntenoverleg EVR. Laad en loshandelingen. KO 20-2. The Hague: Ministry of Housing, Spatial Planning and the Environment , 1989.

[KO 19-2] Knelpuntenoverleg EVR. Toepassen van het subselectie systeem bij een EVR-plichtige inrichting met schepen. KO 19-2. The Hague: Ministry of Housing, Spatial Planning and the Environment, 1989.

[KO 20-2] Het gebruik van parameters in de risico-analyse. KO 20-2. The Hague: Ministry of Housing, Spatial Planning and the Environment, 1989.

[KO 22-5] Knelpuntenoverleg EVR. QRA ladende en lossende schepen. KO 22-5. The Hague: VROM, 1990

[KO 24-2] Gebruik toxiciteitsgegevens. KO 24-2. The Hague: Ministry of Housing, Spatial Planning and the Environment 1989.

[KO 59] Gebruik toxiciteitsgegevens. Ammoniakprobitfunktie. KO 59. The Hague: Ministry of Housing, Spatial Planning and the Environment, 1992.

[KO 86] Gebruik toxiciteitsgegevens. Probitfunctie fosgeen. KO 56. The Hague: Ministry of Housing, Spatial Planning and the Environment, 1994.

[NATO92] Manual of NATO safety principles for the storage of military ammunition and explosives (AC258), Allied Ammunition Storage and Transport Publication 1 (AASTP-1), May 1992.

[Le95] Leeuwen C.J. van, and Hermens J.L.M. (eds.). Risk assessment of chemicals: an introduction. Dordrecht: Kluwer Academic Publishers, 1995.

[NM86] Werkgroep Verspreiding Luchtverontreiniging. Invloed van een gebouw op de verspreiding van schoorsteenpluimen. Delft: Vereniging Lucht, 1986.

[NNM98] Het Nieuw Nationaal Model. Infomil: Den Haag, 1998.

[NR] Nadere Regels met betrekking tot rapport inzake de externe veiligheid (ministeriële regeling d.d. 3 februari 1989, Stcrt. 31). The Hague: SDU, 1989.

[P 172] Arbeidsinspectie. Arbeidsveiligheidsrapport; leidraad aanwijzing AVR-plichtige installaties. Publikatie P 172-1. Voorburg: Ministry of Social Affairs and Employment, 1988[1].

[Pe84] Perry R.H., Green D.W. and Maloney J.O. (eds.). Perry's Chemical engineers' handbook. New York: McGraw-Hill, 1984[6].

[Ph69] Phillips C.A.G. and Warwick R.G. A survey of defects in pressure vessels built to high standards of construction and its relevance to nuclear primary circuits. UKAEA AHSB(S) R162, 1969.

[Re88] Reid R.C., Prausnitz J.M. and Poling B.E. The properties of gases and liquids. New York: McGraw-Hill, 1988[4].

[RIVM99] RIVM. SERIDA. Safety Environmental Risk Database. Bilthoven: RIVM, 1999.

[SA75] Science Applications Inc. LNG terminal risk assessment study for Los Angeles, California. Report prepared for western LNG Terminal Company, 1975

[SAVE97] SAVE. Handleiding protocol voor het uitvoeren van een QRA voor goederenemplacementen. Apeldoorn: SAVE , 1997

[Sm74] Smith T.A. and Warwick R.G. The second survey of defects in pressure vessels built to high standards of construction and its relevance to nuclear primary circuits. Safety and Reliability Directorate, SRD R30, 1974.

[SRPI96] BIOMOVS II Steering Committee. An overview of the BIOMOVS II Study and its Findings. Stockholm; Swedish Radiation Protection Institute, 1996.

[SRS] SRS Data bank.

[SZW97] Beleidsregels arbeidsomstandighedenwetgeving. Besluit van de Staatssecretaris van Sociale Zaken en Werkgelegenheid van 27 juni 1997, Directie Arbeidsomstandigheden, Arbo/AIS 9701436 tot vaststelling van beleidsregels op het gebied van de Arbeidsomstandighedenwetgeving (Beleidsregels arbeidsomstandighedenwetgeving). Supplement van de Nederlandse Staatscourant van 27 juni 1997. The Hague: SDU, 1997.

[Ta98] Taylor J.R./ Taylor Associates ApS. Review of failure rate data for risk analyses. Version 1 Issue 1. Glumsoe: Neste and Taylor Associates ApS, 1998.

[Ti97] Timmers, P.G.J. Berekening van het in- en extern risico van explosievenopslag met behulp van 'RISKANAL'. Draft, Rijswijk: TNO, 1997.

[TNO83] TNO. LPG Integraal, rapport 1112 Effectmodellen LPG. Apeldoorn: TNO, 1983.

[TNO98a] TNO. Ventilatieonderzoek naar infiltratie en verspreiding van buitenluchtverontreinigingen in woningen bij calamiteiten. Delft: TNO, 1998.

[TNO98b] Logtenberg, M.Th.. Derivation of failure frequencies for LoC cases. TNO report TNO-MEP-R98/501. Apeldoorn: TNO, 1998.

[TNO98c] TNO. Investigation into the consequences of introduction of the third version of the yellow book. TNO Report TNO-MEP-R98/457. Apeldoorn: TNO, 1998.

[TNO98d] J.M. Ham and H.H. Schoten. Damage determining effects of BLEVE's. TNO-MEP note 1999IV/38-29171/HAJ/mba. Apeldoorn: TNO, 1998.

[VITO97] Gheys K.. Onderzoek van berekeningsmethoden voor fysische effecten van het incidenteel vrijkomen van gevaarlijke stoffen. Eindrapport. VITO: Antwerpen, 1997.

[VVoW95] Systematiek voor indeling van stoffen ten behoeve van risico-berekeningen bij het vervoer van gevaarlijke stoffen. Project Veilig Vervoer over Water; Deelproject S3b. The Hague: Ministry of Transport, Public Works and Water Management, 1995

[We76] Welker J.R. *et al.* Fire safety aboard LNG vessels. NTIS AD/A - 030 619, 1976

[Wi98] Witlox H.W.M. Modelling of building-wake dispersion. Londen: DNV Technica, 1998.

[Ya77] Yaws C.L. Physical Properties. New York: McGraw-Hill, 1977.

GLOSSARY

1% lethality	the boundary where 1% of the population exposed suffers death due to an accident with dangerous substances
atmospheric tank	storage vessel in which the pressure is close to one bar absolute
blanketing	applying a layer of inert gas over a dangerous substance
blast (wave)	a rapidly propagating pressure or shock-wave in the atmosphere, with high pressure, high density and high particle velocity
blast strength	measure used in the multi-energy method to indicate the strength of the blast, indicated by a number ranging from 1 (for very low strengths) up to 10 (for detonative strength)
BLEVE	Boiling Liquid Expanding Vapour Explosion; results from the sudden failure of a vessel containing liquid at a temperature well above its normal (atmospheric) boiling point. A BLEVE of flammables results in a large fire ball.
blocking system	repression system to isolate (part of) an installation to prevent outflow
bund	containment area to restrict spread of liquid
carcinogenic	carcinogenicity; capacity of a chemical to induce cancer
CFD calculation	three dimensional model calculation; the dispersion of gas is calculated by solving the dynamic partial differential equations for a set of control volumes
competent authority	authority licensing the activity with dangerous substances
dense gas	gas which has a higher specific weight than the surrounding ambient air
deposition	absorption of gas or particles by the ground or vegetation
design pressure	pressure for which the installation is designed; the installation should be able to withstand this pressure
detonation	a propagating chemical reaction of a substance in which the propagation of the reaction front is determined by compression beyond the auto-ignition temperature
dispersion	mixing and spreading of gases in air, causing clouds to grow

domino effect	the effect that loss of containment of one installation leads to loss of containment of other installations
dose	a measure of integral exposure
dry deposition	deposition not caused by rain
effective cloud width	the width of a uniform cloud replacing a toxic cloud; the uniforn cloud has a constant probability of death equal to the probability of death on the centre line of the toxic cloud and the same probability integral
entrainment	mixing of (clean) air into a cloud or plume
establishment	the whole area under the control of an operator where dangerou substances are present in one or more installations, including common or related infrastructures or activities
event tree	a logic diagram of success and failure combinations of events used to identify accident sequences leading to all possible consequences of a given initiating event
explosion	a sudden release of energy that causes a blast
exposure	concentration or intensity that reaches the target person, usually expressed in terms of concentration or intensity and duration
failure	a system or component failure occurs when the delivered service deviates from the intended service
fault tree analysis	the evaluation of an undesired event, called the top event of the fault tree. Given the top event, a fault tree is constructed by a deductive (top-down) method of analysis, identifying the cause or combination of causes that can lead to the defined top event
fire ball	a fire, burning rapidly enough for the burning mass to rise into the air as a cloud or ball
flash evaporation	see flashing
flashing	part of a superheated liquid that evaporates rapidly due to a relatively rapid depressurisation, until the resulting vapour/liquid mixture has cooled to below boiling point at the end pressure. Superheat is the extra heat of a liquid made available by decreasing the liquid's temperature, for instance, by vaporisation, until the vapour pressure equals that of the surroundings.

flash fire	the combustion of a flammable vapour and air mixture in which the flame passes through the mixture at a rate less than sonic velocity so that negligible damaging overpressure is generated
FN-curve	log-log graph, where the x-axis represents the number of deaths, N, and the y-axis represents the cumulative frequency of the accidents, with the number of deaths equal to N or more
free field calculation	calculation method in which ignition sources outside the establishment or transport route are not taken into account. If a flammable cloud is not ignited at the establishment, ignition is assumed to occur at maximum cloud area.
frequency	the number of times an outcome is expected to occur in a given period of time (see also probability)
friction velocity	by definition the cube root from (minus) the shear stress at the surface; the shear stress is the stress exerted by the wind on the ground surface due to friction
grid	A network of lines superimposed on a map and forming squares for referencing, the basis of the network being that each line in it is found at a known distance either east or north of a selected origin
grid cell	the area around a single grid point corresponding with the mesh of the grid
grid point	crossing point of two grid lines
hazard	a chemical or physical condition with the potential of causing damage
ignition source	a thing able to ignite a flammable cloud, e.g. due to the presence of sparks, hot surfaces or open flames
indication number	measure of the hazard of an installation, irrespective of its location
individual risk	the probability that in one year a person will become a victim of an accident if the person remains permanently and unprotected in a certain location. Often (also in this report) the probability of occurrence in one year is replaced by the frequency of occurrence per year.
installation	a technical unit within an establishment in which dangerous substances are produced, used, handled or stored.

internal energy	energy present due to storage of a substance above ambient pressure; following rupture of the vessel, part of the internal energy is released as a blast wave
jet	the outflow of material emerging from an orifice with a significant momentum
jet fire	see jet flame
jet flame	the combustion of material emerging from an orifice with a significant momentum
K1 liquid	flammable liquid having a flash point less than 21 °C and a vapour pressure at 50 °C less than 1.35 bar (pure substances) or 1.5 bar (mixtures)
LC_{50}	median lethal concentration , i.e. the concentration of a substance estimated to be lethal to 50% of the test organisms. LC_{50}(rat, inh, 1 h) is the concentration in air estimated to be lethal to rats after one hour of exposure.
lee	location/site downwind of a building
LFL	lower flammability limit; below this concentration too little flammable gas is present in the air to maintain combustion
limit value	measure of the dangerous properties of a substance based on both the physical and the toxic/explosive/flammable properties of the substance
liquid head	vertical distance between the liquid level and the location of the hole
liquefied pressurized gas	see pressurized liquefied gas
Loss of Containment event	event resulting in the release of material to the atmosphere
LOC	see Loss of Containment event
maximum occurring pressure	maximum pressure that can occur in an installation
model intercomparison	comparison of the results of two models for a test case
Monin-Obukhov length	length-scale which characterises the atmospheric stability
nominal pumping rate	normal flow of material through a pump
non-obstructed region	region where jet outflow does not interact with objects

obstructed outflow	region where a jet outflow does interact with objects
operator	any individual or corporate body who operates or holds an establishment or installation or, if provided for by national legislation, has been given decisive economic power in the technical operation thereof (Chapter 2); also defined as any individual operating technical equipment (Chapter 4)
outflow	see release
Pasquill class	classification to qualify the stability of the atmosphere, indicated by a letter ranging from A, for very unstable, to F, for stable
passive dispersion	dispersion solely caused by atmospheric turbulence
plume	cloud of material following a continuous release to the atmosphere
pool	layer of liquid on a subsoil or on a water surface
pool fire	the combustion of material evaporating from a layer of liquid at the seat of the fire
pressure vessel	storage vessel in which the pressure is (substantially) more than 1 bar absolute
pressure relief device	valve or bursting disc, designed to relieve excessive pressure automatically
pressurized liquefied gas	gas that has been compressed to a pressure equal to saturated vapour pressure at storage temperature, so that the larger part has condensed to the liquid state
primary container	container holding the substance and in direct contact with it
probability	measure of the likelihood of an occurrence, expressed as a dimensionless number between 0 and 1. Risk is defined as the probability that within a fixed time period, usually one year, an unwanted effect occurs. Consequently, risk is a dimensionless number. However, risk is often expressed in units of frequency, ‘per year’. Since failure frequencies are low, the probability that an unwanted effect will occur within a fixed time period of one year is, practically speaking, equal to the frequency of occurrence per year. In this report, frequency is used to denote the risk.
probability integral	integral of the probability of death over the co-ordinate perpendicular to the plume axis

probit	number directly related to probability by a numerical transformation
process vessel	vessel in which a change in the physical properties of the substance occurs, e.g. temperature or phase
PROTEUS	model to calculate the risk to surface waters and sewage treatment plants
puff	cloud spreading in all directions due to an instantaneous release
QRA	see Quantitative Risk Assessment
quantitative risk assessment	the process of hazard identification followed by a numerical evaluation of effects of incidents, and consequences and probabilities, and their combination into overall measures of risk
rain-out	dropping to the ground of the small liquid drops from that fraction of the flashing liquid initially remaining suspended in the atmosphere
reactive	measure for the flame acceleration in a gas–air mixture
reactor vessel	vessel in which a chemical change of the substances occurs
release	the discharge of a chemical from its containment, i.e. the process and storage equipment in which it is kept
recirculation zone	location/site downwind of a building where uniform mixing is assumed
repression system	system to limit the release of substances into the environment given a loss of containment event
RISAM	model to calculate the risk to surface waters
risk	the unwanted consequences of an activity connected with the probability of occurrence. Often (also in this report) the probability of occurrence is replaced by the frequency of occurrence
risk contour	line on a map connecting points having equal risk
roughness length	artificial length-scale appearing in relationships describing the wind speed over a surface and characterising the roughness of the surface

safety report	report on the safety of an establishment, as required by Council Directive 96/82/EC of 9 December 1996
saturation pressure	the pressure of a vapour which is in equilibrium with its liquid state; also the maximum pressure possible for a vapour at a given temperature
secondary container	container enclosing the primary container, not in direct contact with the substance
selection number	measure of the hazard of an installation at a specific location
side-on overpressure	the pressure experienced by an object as a blast-wave passes by
societal risk	the frequency (per year) that a group of at least a certain size will at one time become victims of an accident
stability	Atmospheric stability; the extent to which vertical temperature (= density) gradients promote or suppress turbulence in the atmosphere
surface friction velocity	see friction velocity
sympathic detonation	domino-effect, where detonation of explosives in one storage room leads to detonation of explosives in other storage rooms
uncertainty	measure of the distinction between the model calculation and the actual situation
validation	Comparison of model results to measurements
vapour cloud explosion	the explosion resulting from ignition of a pre-mixed cloud of flammable vapour, gas or spray with air, in which flames accelerate to sufficiently high velocities to produce significant overpressure
VERIS	model to calculate the risk to surface waters
wall roughness	measure (in metres) to express the influence of the pipe wall on the flow through the pipe
wet deposition	deposition caused by rain

Note: Several definitions have been taken from the 'Red Book' [CPR12E], the 'Yellow Book' [CPR14E], Chambers [Ch88], Council Directive 96/82/EC [EU96] and Van Leeuwen and Hermens [Le95].

SYMBOLS

Chapter 2

Δ	Amount added in the calculation of the factor O_3 to account for liquid pool evaporation (-)
A	Indication number (-)
A^F	Indication number for flammable substances (-)
A^T	Indication number for toxic substances (-)
G	Limit value (kg)
L	Distance between an installation and the location where a selection number is calculated (m)
LC_{50}	Lethal concentration at which 50% of the exposed test animals suffer death (mg m^{-3})
I_i	Sample installation (-)
O_1	Factor to account for the type of installation, storage or process (-)
O_2	Factor to account for the positioning of the installation (-)
O_3	Factors to account for the process conditions (-)
P_i	Partial vapour pressure at process temperature (bar absolute)
P_{sat}	Saturation pressure at process temperature (bar absolute)
Q	Quantity of a substance present (kg)
Q_x	Qualifying quantity of substance x for application of Article 9 of Council Directive 96/82/EC of 9 December 1996 (tonnes)
q_x	Quantity of substance x present or likely to be present for application of Article 9 of Council Directive 96/82/EC of 9 December 1996 (tonnes)
S	Selection number (-)
S^T	Selection number for toxic substances (-)
S^F	Selection number for flammable substances (-)
T_p	Process temperature (°C)
T_{bp}	Atmospheric boiling point (°C)
X	Factor in O_3 to account for saturation pressure at process temperature (-)

Chapter 4

Note: The symbols used in Appendix 4.A are listed there.

χ	Adiabatic flash fraction (-)
ε	Wall roughness (m)
η	TNT-equivalence factor (-)
λ_s	Thermal conductivity (J s^{-1} m^{-1} K^{-1})
ρ_s	Density (kg m^{-3})
ω	Ignition effectiveness (s^{-1})
A	Projection of a building in wind direction (m^2)
A_{bund}	Bund area (m^2)
a_s	Thermal diffusivity (m^2 s^{-1})
b_0	Source radius of the free jet (m)
C_d	Discharge coefficient (-)
C_{rz}	Concentration in the recirculation zone (kg m^{-3})
C_u	Empirical constant used to calculate the length of the free jet (-)
C_{vent}	Concentration in ventilation air (kg m^{-3})
$c_{p,s}$	Specific heat (J kg^{-1} K^{-1})
$D_{rel,i}$	Release duration of time segment i (s)
d	Average traffic density (-)
E	Combustion energy (J)
F	Ventilation rate (m^3 s^{-1})
f	Frequency (y^{-1})
f_{obstr}	Fraction of the total mass in the flammable cloud in an obstructed region (-)
K	Parameter to account for the shape and orientation of the building (-)
L	Monin Obukhov length (m)
L_0	Distance between release point and obstacle (m)
L_j	Length of free jet (m)
M	Mass released (kg)
M_{rel}	Mass released in the first 30 minutes following the LOC (kg)
M_{seg}	Mass released in a time segment (kg)
N	Number of vehicles per hour (h^{-1})
N_{seg}	Number of time segments (-)
n	Average number of people present in a grid cell (-)

$P(t)$	Probability of ignition in time interval 0 – t (-)
P_a	Ambient pressure (N m^{-2})
P_{BLEVE}	Probability of a BLEVE given an instantaneous release of a flammable gas with direct ignition (-)
$P_{d.i.}$	Probability of direct ignition (-)
P_i	Probability of an obstructed outflow (-)
$P_{present}$	Probability that an ignition source is present (-)
Q_{out}	Mass outflow to the atmosphere following a release inside a building (kg s^{-1})
$Q_{rel,i}$	Mass outflow in time segment i (kg s^{-1})
$R_{0.3\ barg}$	Distance to the peak- side on overpressure contour of 0.3 barg (m)
$R_{0.1\ barg}$	Distance to the peak- side on overpressure contour of 0.1 barg (m)
R_{pool}	Effective pool radius (m)
$r'_{0.3\ barg}$	Combustion energy scaled distance to the peak- side on overpressure contour of 0.3 barg (-)
$r'_{0.1\ barg}$	Combustion energy scaled distance to the peak- side on overpressure contour of 0.1 barg (-)
s	Co-ordinate along the jet axis (m)
t	Time (s)
t_{av}	Averaging time (s)
t_{react}	Time for a repression system to become effective (s)
t_{rel}	Duration of a release (s)
u	Wind speed (m s^{-1})
u^*	Friction velocity (m s^{-1})
u_0	Velocity of the jet at the source (m s^{-1})
u_{air}	Average ambient wind velocity (m s^{-1})
u_c	Velocity of the jet (m s^{-1})
V	Volume of a room (m^3)
v	Average velocity of vehicle (km h^{-1})
z_0	Roughness length (m)

Chapter 5

a	Probit constant describing the toxicity of a substance (-)
b	Probit constant describing the toxicity of a substance (-)
C	Concentration of a toxic substance (mg m^{-3})
F_E	Fraction of the population dying (-)
$F_{E,in}$	Fraction of the population indoors who die (-)
$F_{E,out}$	Fraction of the population outdoors who die (-)
$f_{pop,in}$	Fraction of population present indoors (-)
$f_{pop,out}$	Fraction of population present outdoors (-)
n	Probit constant describing the toxicity of a substance (-)
Q	Heat radiation (W m^{-2})
P	Probability (-)
P_E	Probability of death (-)
P_i	Probability of ignition event i (-)
P_{peak}	Peak overpressure (bar gauge)
Pr	Probit (-)
t	Exposure time (min)

Chapter 6

$\Delta IR_{S,M,\varphi,i}$	Contribution to the individual risk of LOC, S, weather class, M, wind direction, φ, and ignition event, i (y^{-1})
$\Delta N_{S,M,\varphi,i}$	Expected number of deaths in a grid cell of LOC, S, weather class, M, wind direction, φ, and ignition event, i (-)
ΔT	Time step (s)
α	angle (-)
μ	angle (-)
θ	angle (-)
σ_y, σ_z	Dispersion coefficients (m)
C(R,t)	Concentration of a toxic substance on the centre line (mg m^{-3})
ECW(R)	Effective cloud width at distance R (m)
$F_{cl}(R)$	Fraction of deaths on the centre line at distance R (-)
F_d	Fraction of people dying, given LOC, S, weather class, M, wind direction, φ, and ignition event, i (-)

$F_{E,in}$	Fraction of the population indoors who die(-)
$F_{E,out}$	Fraction of the population outdoors who die (-)
F_N	Summed frequency of events with N or more people dying (y^{-1})
$f_{pop,in}$	Fraction of population present indoors (-)
$f_{pop,out}$	Fraction of population present outdoors (-)
f_S	Frequency of LOC, S (y^{-1})
$f_{S,M,\varphi,i}$	Frequency of LOC, S, weather class, M, wind direction, φ, and ignition event, i (y^{-1}
IR	Individual risk at a point (y^{-1})
N_{cell}	Number of people in a grid cell (-)
$N_{S,M,\varphi,i}$	Expected number of deaths of LOC, S, weather class, M, wind direction, φ, and ignition event, i (-)
n_{ws}	Number of wind sectors (-)
P(R,y)	Probability of death off-axis at distance R (-)
P_φ	Probability of wind direction φ (-)
P_{ci}	Probability a grid point is covered by the effective cloud (-)
$P_{cl}(R)$	Probability of death on the centre line at distance R (-)
P_d	Probability of death at a point (-)
P_M	Probability of weather class M (-)
PI(R)	Probability integral at distance R (m)
R	Distance between grid point and source (m)
x	Co-ordinate along the centre line of the plume (m)
y	Co-ordinate perpendicular to the centre line of the plume (m)
z	Height co-ordinate (m)

Guideline

for

Quantitative Risk Assessment

Part two: Transport

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SAVE

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MANUAL FOR RISK ANALYSIS OF TRANSPORTATION ACTIVITIES, PREFACE

This manual for risk analysis of transportation activities gives the state-of-the-art, and is based on analyses of accident reports and agreements on parameter values between all parties involved, both governmental authorities and transport operators. Agreement has been reached through a process for which the Dutch Ministry of Transport has final responsibility.
The application of this part of the manual and its rules for the execution of risk studies is restricted to the transport of dangerous goods on public routes for vehicles, trains and water transport, and to pipelines outside the boundary limits of plants and terminals, and shunting yards owned and operated by railway operators such as Dutch Railways.
The models and data within this part of the manual are specific for transportation activities outside plants and terminals. They are therefore not to be applied in risk analyses for transportation activities and/or stationary equipment within plants and terminals.

1. SELECTION OF RELEVANT ROUTE SECTIONS

1.1 Introduction

In order to evaluate whether the risk of transporting hazardous substances along a specific route complies with external safety criteria, the individual risk and the societal risk should be calculated. Fortunately it is not always necessary to perform a detailed, time-consuming and costly QRA. Insight into the level of risk for a specific route section may be gained by applying the following three steps, which are increasingly detailed:

1. Comparing the frequencies of annual transport movements with threshold values gives a first quick scan of the risk levels. When the annual frequency of transport movements along the route is less than the threshold value a quantification of the external safety risks is not needed. In such cases no external safety problem formally exists although, of course, incidents with release of hazardous materials still may occur. Whenever the threshold values are exceeded or are not applicable for the specific situation, a quantification of the risk should be made.
2. At first the risk may be relatively simply estimated by using IPORBM (chapter 2). IPORBM quantifies the risk in terms of individual risk and societal risk and comparison to the Dutch external safety criteria is straightforward. Although IPORBM usually produces results with adequate precision, specific situations may require an even more accurate and detailed risk calculation as described in chapter 3. Currently no general guidelines can be given as to whether an IPORBM calculation is sufficient, or whether a more detailed analysis is required. Complex situations differing from the simple standard situation assumed in IPORBM should be treated with care. In particular, a more detailed analysis will be necessary in cases where the calculated results approximate to the specified risk criteria, or where the outcome of a calculation is of crucial importance to the safety issue involved and will therefore be heavily debated. In these cases a specific risk calculation should be made.
3. Performing a detailed QRA, as outlined in chapter 3.

In the following paragraphs the threshold values for the frequency of transport movements on roads (paragraph 1.2), railways (paragraph 1.3) and inland waterways (paragraph 1.4) are given. These thresholds provide a quick selection of those situations where further consideration and quantification of the external safety risks are appropriate. The thresholds given are conservative in that they ensure that every situation that might be relevant with respect to non-compliance to the Dutch external safety criteria will be considered. Thresholds for the transport of hazardous materials by pipeline are described in [VNG98].

1.2 Threshold values for roads

It appears that the external risk of road transport in the Netherlands is strongly dominated by the transport of LPG [AVIV97]. The threshold values are therefore given in terms of the annual frequency of transport movements of the substance category GF3 which are flammable gases like LPG. The following road typology is used:
- Motorways
- Non-urban roads
- Urban roads

1.2.1 Individual risk

Table 1.1 gives the threshold values for annual frequencies for LPG transport movements and for all hazardous substances below which no 10^{-6} individual risk contour exists.

Table 1.1 Threshold values below which no 10^{-6} individual risk contour exists

Road type	Threshold for LPG (movements/year)	Threshold for all hazardous substances (movements/year)
Motorway	6500	27000
Non-urban	2300	7500
Urban	8000	22000

Notes:

1. The thresholds should be checked first for LPG and then for all hazardous substances.
2. The thresholds apply to an open road situation (no obstacles) and average road safety. When experience indicates that the local accident rate is increased, such as at a level crossing, the thresholds should be applied with caution and a more detailed quantification of the risks should be made.
3. “All hazardous substances” means substances categorised in one of the substance categories: flammable liquid (LF), flammable gas (GF), toxic liquid (LT) or toxic gas (GT) according to [AVIV95].
4. The threshold values given for all hazardous substances apply to a broad range of combinations of transported substances, except when there are significant numbers of toxic substances being transported. Then the thresholds are not applicable and a more detailed quantification of the risks should be made. For guidance, the annual frequencies required tot give an individual risk exceeding 10^{-6} per year for toxic substances is given in Table 1.2.

Table l.2 Threshold values required to give an individual risk exceeding 10^{-6} per year

	Movements/year		
Substance category	**Motorway**	**Non-urban**	**Urban**
GT2 or GT3	8000	3000	10000
GT4 or GT5	4000	2000	8000
LT2	10000	3000	8000
LT3	2000	700	2000
LT4	700	300	800

1.2.2 Societal risk

The societal risk is also dominated by the transport of liquefied, pressurised, flammable gases, mainly LPG. The societal risk depends on the annual frequency of transport movements and on the distance and density of the population along the road. Table 1.3 gives the threshold below which the annual frequency of LPG transport movements for a particular population density along a specified route does not lead to a societal risk that exceeds the societal risk criterion. Thresholds for all hazardous substances are given in Table 1.4.

Table 1.3 Threshold values below which the societal risk criterion is not exceeded

Population density (pers/ha)	**Threshold for LPG (movements/year)** (one-sided development)		
	Motorway	Non-urban	Urban
100	500	200	500
90	600	200	700
80	700	200	800
70	900	300	1100
60	1300	400	1500
50	1800	600	2000
40	2800	1000	3500
30	5100	1800	6000
20	11000	4000	13500
10	45500	16000	53000

Table 1.4 Threshold values below which the societal risk criterion is not exceeded

Population density (pers/ha)	**Threshold for all hazardous substances (movements/year)** (one-sided development)		
	Motorway	Non-urban	Urban
100	2500	900	3500
90	3500	1200	4000
80	4000	1500	5000
70	5500	2000	6500
60	7500	2500	9000
50	10500	4000	13000
40	16500	6000	20500
30	29500	10500	36500
20	66500	23500	82000
10	266000	94000	326000

Notes:

1. The thresholds should be checked first for LPG and then for all hazardous substances.
2. The thresholds are conservatively formulated i.e. the development (population) is assumed to be directly adjacent to the road.
3. The population density is determined as the average density within 200 meters from the road edge. When the maximum density is more than three times the average, the maximum value should be used instead.
4. When the development (population) is on both sides of the road, the frequencies should be divided by a factor of 4.

5. The thresholds apply to an open road situation of average road safety. When local experience indicates that the accident rate may be higher, such as at a level crossing, the thresholds should be applied with caution. A more detailed quantification of the risks using IPORBM should be made.
6. The threshold values given apply to a broad range of combinations of transported substances. Only when very toxic substances are being transported, such as the categories LT3, LT4, or GT5, the thresholds are not applicable and a detailed quantification of the risks using IPORBM should be made.

1.3 Threshold values for railways

The external risk of the transport of hazardous substances by rail is dependent on the substances transported and the track characteristics, notably train speed. The following typology of railway tracks is used:
- High speed tracks (>40 km/hr)
- Low speed tracks (<40 km/hr).

The substances are categorised in a scheme that is (for historical reasons) specific for railway transport. This categorisation is solely based on the Kemler code of the substance.
The categories for railway transport are given in Table 1.5.

Table 1.5 Substance categories for railway transport

Substance category	Kemler code	Note
A	23, 263, 239	Flammable gas, liquefied under pressure, such as LPG
B2	26, 265, 268 (chlorine excluded)	Toxic gas, liquefied under pressure, such as ammonia
B3	chlorine itself	Extremely toxic gas, liquefied under pressure, like chlorine
Chlorine	chlorine itself	In dedicated chlorine trains
D3	Acrylonitrile itself	Toxic liquid, such as acrylonitrile
D4	66, 663, 668, 886, X88, X886	Extremely toxic liquid, such as hydrogen fluoride
C3	33, 336 (Acrylonitrile excluded), 338, 339, X323, X333, X338	Extremely flammable liquid, such as motor spirit

1.3.1 Individual risk

Table 1.6 gives the threshold annual values for C3 transport movements and for all hazardous substances below which no 10^{-6} individual risk contour exists.

Table 1.6 Threshold annual values below which no 10^{-6} individual risk contour exists

	TRACK TYPE	
	High speed	**Low speed**
Threshold for C3 (rail cars/year)	3000	10^{-6} not exceeded
Threshold for all hazardous substances (rail cars/year)	7000	10^{-6} not exceeded

Notes:

1. The thresholds should be checked first for C3 and then for all hazardous substances.
2. The thresholds apply to moving rail cars and open track situations (no tunnels, no obstacles). For shunting yards and private sidings a specific calculation methodology is available (see chapter 3.3)
3. For low speed tracks more than 55,000 transport movements annually are required for an individual risk exceeding 10^{-6} per year. For Dutch standards this is unrealistically high. Therefore thresholds for low speed tracks are not presented.
4. "All hazardous substances" means substances categorised in one of the substance categories specified in Table 1.5.
5. The threshold values given apply to a broad range of combinations of transported substances. However, when significant numbers of toxic liquids in the category D3 or D4 are being transported the thresholds are not applicable and a more detailed quantification of the risks should be made. For guidance, the annual frequencies needed for high speed tracks to generate an individual risk higher than 10^{-6} per year for category D3 and D4 are 13,000 and 9,000 respectively.

1.3.2 Societal risk

The societal risk depends upon the annual frequency of transport movements and on the distance and density of the population along the track. The level of the societal risk is strongly dependent on the presence of extremely toxic pressurised gases.

The societal risk criterion may be exceeded when the annual frequency of rail cars exceeds the values mentioned in Table 1.7.

Table 1.7 Threshold values for transport of toxic gases below which the societal risk criterion is not exceeded

	Track type	
Substance category	High speed	Low speed
B3 (rail cars/year)	60	2000
Chlorine (rail cars/year)	300	8000

Table 1.8 gives the thresholds below which the annual frequency of LPG transport movements for the population density along the specified route does not lead to a societal risk that exceeds the societal risk criterion. Thresholds for all hazardous substances are also given.

Table 1.8 Threshold values below which the societal risk criterion is not exceeded

Population density (pers/ha)	**Threshold for LPG (rail cars/year)**		**Threshold for all hazardous substances (rail cars/year)**	
	High speed track	Low speed track	High speed track	Low speed track
100	1600	8000	7500	37500
90	2000	10000	9000	46000
80	2500	12500	12000	58500
70	3000	16000	15000	76500
60	4500	22000	21000	104000
50	6500	32000	30000	150000
40	10000	50000	47000	234000
30	20000	88000	83000	416000
20	40000	200000	187000	

Notes:

1. The thresholds should be checked first for the extremely toxic gases, then for LPG, then for all hazardous substances.
2. The thresholds are conservatively formulated i.e. the development (population) is assumed to be directly adjacent to the track.
3. The population density is determined as the average density within 200 meters from the track. When the maximum density is more than three times the average, the maximum value should be used instead.
4. Table 1.8 is for one-sided developments of the area along the track. When the development (population) is on both sides of the track, the frequencies should be divided by a factor of 4.
5. The thresholds apply to moving rail cars and open track situations (no tunnels, no obstacles). For shunting yards and private sidings a specific calculation methodology is available (see chapter 3.3).
6. “All hazardous substances” means substances categorised in one of the substance categories specified in Table 1.5.

1.4 Threshold values for inland waterways

Inland waterways are characterised by navigability class according to the CEMT convention. The navigability class defines a maximum size of vessel in relation to the dimensions of the waterway. The main waterways fall into the CEMT classes 4, 5 and 6. Navigability classes for specific waterways are given in Table 1.9 and may also be found in [AVV97a].

Table l.9 Navigability classes for specific waterways

Waterway	Class	Waterway	Class
Eemskanaal	5	Waal	6
V Starckenborghkanaal	5	Beneden Merwede	6
Prinses Margrietkanaal	5	Noord	6
IJssel	5	Hollandsch Diep	6
Nederrijn	5	Schelde-Rijnkanaal	6
Lek	5	Maas	5
Amsterdam-Rijnkanaal	6	Julianakanaal	5
Nieuwe Maas	6	Kanaal Gent-Terneuzen	6
Oude Maas	6	Hollandsche Ijssel	5
Oude Rijn/Gouwe	4		

The accident rate depends on the navigability class. However, the accident rate may vary by several orders of magnitude between sections of the same waterway due to the presence of local factors. The use of thresholds for the annual transport movements is therefore more problematic than for the other modes of transport. The thresholds given should therefore be used with extreme caution, and one should be attentive to the presence of factors indicative of an increased local accident rate.
Transport of hazardous substances on the class 4 and 5 waterways consists mainly of flammable liquids. On class 5 and 6 waterways toxic substances are also encountered.

1.4.1 Individual risk

The individual risk near the waterway is dominated by the transportation of flammable liquids. Threshold values for the frequency of annual transport movements for substance category LF2, below which no 10^{-6} individual risk contour exists, are given in Table 1.10.

Table 1.10 Threshold values below which no 10^{-6} individual risk contour exists

Navigability class	**Threshold for substance category LF2 (movements/year)**
4	7000
5	6500
6	3000

Notes:
1. The thresholds apply to a situation of average traffic safety. When local nautical experience indicates that the accident rate may increase due to the presence of a bend with a limited view, or a dock or harbour entrance, or other such factors, the threshold values given should be applied with extreme caution. A more detailed quantification of the risks using IPORBM should be made. The same applies to situations in which the distribution of traffic over the width of the waterway deviates significantly from a uniform one.

1.4.2 Societal risk

Societal risk depends upon the annual frequency of transport movements and on the distance and density of the population along the waterway. lt appears that the societal risk in the Netherlands is dominated by the transport of toxic substances. The thresholds are therefore formulated in two instances:

1. When extremely toxic liquids LT3 or LT4 are transported, the societal risk should always be quantified.
2. Table 1.11 gives the threshold values for the annual transport movements of ammonia (liquefied under pressure) which, in combination with the given population density along the route, does not lead to a societal risk that exceeds the societal risk criterion.

Table 1.11 Threshold values below which the societal risk criterion is not exceeded

Population density (pers/ha)	**Threshold for liquefied ammonia under pressure (movements/year)** (one-sided development)		
	Navigability-class 4	Navigability-class 5	Navigability-class 6
100	6000	4500	2000
90	7500	5500	2500
80	9500	7000	3000
70	12000	9000	4000
60			5500
50			8000
40			12000
30			22000

Notes:

1. The threshold values apply to a situation of average traffic safety. When local nautical experience indicates that the accident rate may increase due to the presence of a bend with a limited view, or a dock or harbour entrance, or other such factors, the threshold values given should be applied with extreme caution. A more detailed quantification of the risks should be made. This also applies to situations in which the distribution of traffic over the width of the waterway deviates significantly from a uniform one.
2. When the development (population) is on both sides of the waterway, the frequencies should be divided by a factor of 2.
3. If ammonia is transported in semi-pressurised tankers (temperature below 278 K) no threshold values apply. The societal risk does not exceed the societal risk criterion.

2. IPORBM

2.1 Introduction

IPORBM is the Dutch acronym for Inter Province Committee for Risk Calculation Methodology. AVIV BV consultants have developed the IPORBM software program. It is a standardised calculation methodology for determining the external risks involved when transporting hazardous substances (flammable and toxic gases and liquids in bulk) by road, railway, waterway or pipeline [IPORBM]. This risk calculation methodology offers a means for quickly calculating the risk level along a defined transport route, based on a limited amount of input data. A method to identify the transport routes and specific locations where a risk calculation should be made is described in chapter 3. In this chapter a description of the program IPORBM and the required input data for each transport modality will be given. Sources where the required input data, regarding the transport systems, transport streams, accident frequencies and population densities may be obtained are described in chapter 4.

Although IPORBM usually produces results with adequate precision, specific situations may require an even more accurate and detailed risk calculation (QRA) described in chapter 3. As it is, no general guidelines can be given as to whether an IPORBM calculation is sufficient, or a more detailed analysis is required. Specific situations, which differ from the standard situation assumed in IPORBM and described below, should be treated with care. In particular, a more detailed analysis will be necessary in cases where the calculation results approximate to a certain predetermined criterion, or where the outcome of a calculation is of crucial importance to the safety issue involved and will therefore be heavily debated. Some of the default values of the parameters in the program may be changed to meet the requirements of a specific situation.

2.2 IPORBM: a general description

The program is set up to determine the societal risk and the individual risk resulting from the transport of hazardous substance categories along a certain route, called a “trajectory” (route section). In IPORBM all “trajectories” (route sections) are defined as straight lines and it is assumed that no obstacles such as tunnels, or sound barriers, are present (open route). For certain specific situations, for example if obstacles are present, the route is elevated, or there are sharp bends in the route, IPORBM will not give adequate results and a more detailed calculation may be appropriate.

In IPORBM the diversity of substances transported is reduced to a smaller range of substance categories by using standard categories containing substances with similar risk factors. Each substance category is characterised by a specific example substance. This categorisation of substances is outlined in chapter 4 and, amongst other things, is based on aggregation, volatility, flammability and toxicity. For pipelines, risks can only be calculated in IPORBM for a limited number of substances, and combinations of pipeline diameter and pipeline operating pressures.

In IPORBM the transport risks of every transport mode are characterised by a limited number of representative loss of containment events (LOCs) and a limited number of typical transport units and transport route characteristics. These LOCs have been derived from a number of reports and are described in detail in chapter 3 and in [IPORBM]. In IPORBM a minor and a major LOC is usually defined. The physical effects of these LOCs and resulting events (scenarios) have been calculated beforehand in IPORBM for the six fixed weather types given in Table 2.1.

Table 2.1 Weather types used in IPORBM

Weather class (Pasquill class, wind speed)	Daytime probability	Night-time probability
B3.0	0.220	0.000
D1.5	0.122	0.149
D5.0	0.299	0.262
D9.0	0.359	0.261
E5.0	0.000	0.112
F1.5	0.000	0.216

Fixed parameters were used characterising the surroundings of the transport route, the transport unit, and the release and dispersion of the hazardous substance. The results of these calculations have been entered into a result matrix. In this way, the program only has to perform a limited number of calculations for a complete risk evaluation. The user has no further control over accident scenarios or effect calculations. The user of the program merely enters a description of the route section, the type of route section (route characteristics), the population data, the annual frequency of transport movements per substance and transport category, ignition probabilities and the probabilities of the six weather types, from which calculations are made. Wind direction cannot be taken into account because a uniform probability is assumed in IPORBM. The use of specific accident frequencies is recommended. If default values for the accident frequencies are used, it should be ascertained whether this leads to an over- or under-estimation of the risks.

Population density is indicated in IPORBM by rectangles along the route, with a uniform population density per rectangle. Input parameters include the size of these rectangles, the distance from either side of the route (measured from the axis of the transport route), and the average population density per rectangle. Situations where large groups of people are present during short periods of time, as in stadiums, should be addressed in a specific calculation.

The population density and the transport movements often depend on the time of the day. The population density can be divided into day and night fractions. Also, the fractions of the transport movements that take place during the day and night can be specified. Chapter 3 outlines how, and to what level of detail, population densities must be specified.

In the case of flammable gases and liquids, an immediate and a delayed ignition probability are defined for each minor and major outflow (LOC). Default values for each transport mode are given in the next sections. In individual risk calculations, the gas cloud is assumed to ignite at its maximum size. In societal risk calculations, the time of ignition depends on the presence of ignition sources. The maximum probability of a delayed ignition of the gas cloud is equal to the value entered. For delayed ignition calculations two options are available. The user can define whether the ignition probability is dependent on the population density under the developing gas cloud or is also a function of the travel time of the gas cloud. The first option is recommended.

Situations may occur where other types of ignition sources, such as traffic and industry related sources, are present and the approximation used in IPORBM falls short. A more appropriate detailed calculation should be considered.

After entering all the required input data and the program has performed the calculation, the results are displayed as individual risk contours along the total transport route, and as societal risk graphs per kilometre section. Input data and calculation results can be saved to disk. Calculation results can be displayed on the screen as text, as societal risk graphs (also known as FN curves), and as individual risk contours. Graphical representations of the results can be printed using a printer or a plotter. The contribution of the different substance categories to the overall risks can be shown.

2.3 Road

The required input data for road transport are visualised in Figure 2.1 and Figure 2.2. In IPORBM, the road transport system is described using a predefined road type, the length of the road section, and the annual frequency of movements of fully loaded transport for categories of substances (combination of transported substances: LF-GT) and the population data along the transport route. The daytime fraction of the total transport movements can also be defined. This ratio indicates the transport fraction that takes place during the meteorological day. For road transport, this fraction has a default value of 0.8 (80%). The probability of an outflow of a hazardous substance of a certain magnitude is dependent on the type of road and the type of transport unit. IPORBM contains default outflow frequency values for pressurised tankers and atmospheric tankers, for each of four road types. These types are motorways, outside built-up area, inside built-up area, and generic. The user can, however, supply alternative outflow frequencies for atmospheric tankers for specific route sections (for pressurised tankers the outflow frequencies are determined by IPORBM, based on a fixed ratio between atmospheric and pressurised tankers). The procedure for determining location specific outflow frequencies using location specific injury accident frequencies is outlined in chapter 4. Default ignition probabilities are shown in Figure 2.2. In the case of a pool fire the delayed ignition effects are assumed to be equal, and the immediate and delayed ignition probabilities are added. The default values are recommended, although the default values for the ignition probabilities may be changed.

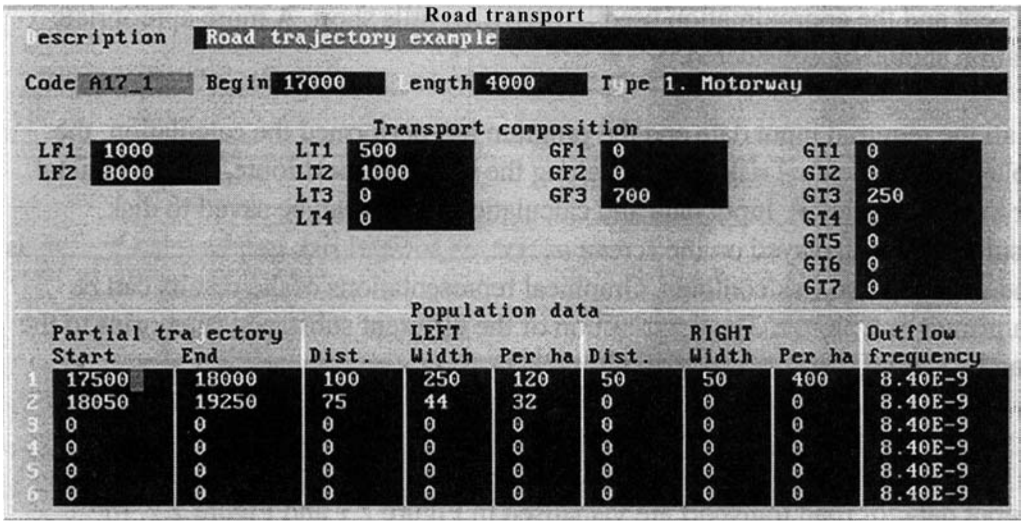

Figure 2.1 The road modality main entry screen

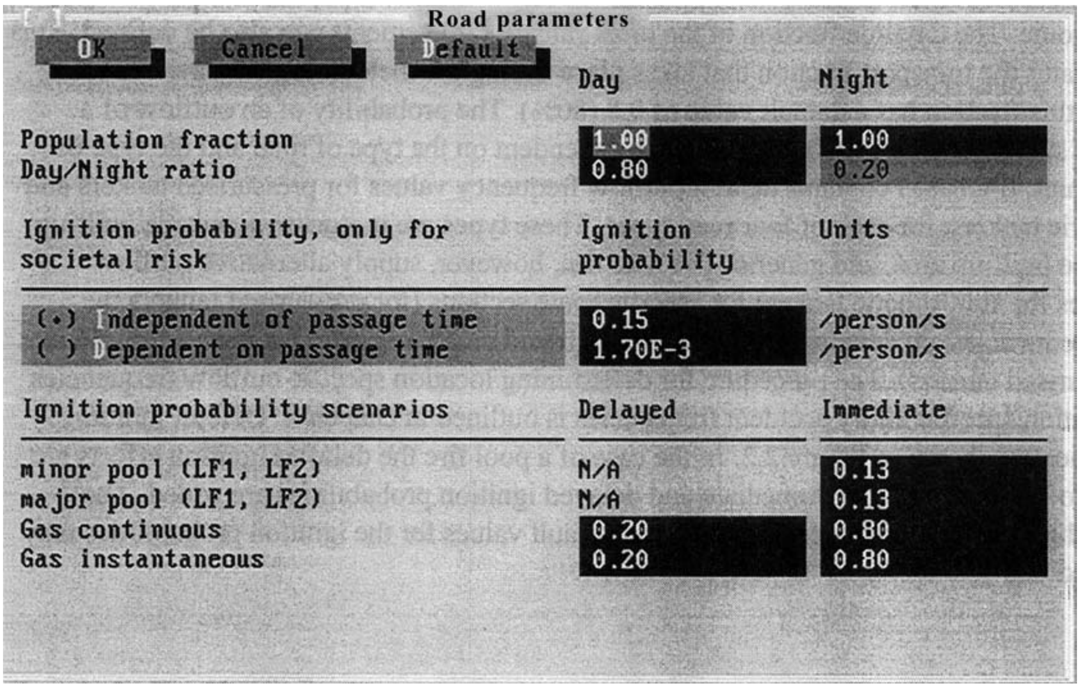

Figure 2.2 The Road Parameters dialog box

2.4 Rail

The Dutch railway system may be seen as an assembly of shunting yards, open tracks and private sidings (chapter 3.3). IPORBM addresses the risks associated with the transport by rail of hazardous substances, flammable and toxic gases and liquids in bulk, in moving cars for open track situations. However, the user should bear in mind that accidents related to the arrival and departure of trains (to be) shunted at yards, to and from open tracks, are not considered in

IPORBM. Therefore, for locations in the proximity of shunting yards, a detailed QRA has to be made.

In IPORBM, the rail transport system is described by the railway route section type, the length of this section, the type of train in which the hazardous substances are transported, the annual frequency of transport movements for each substance category and type of train, and the population data along the route. The required input data for rail transport are visualised in Figure 2.3 and Figure 2.4.

Six substance categories (A, B2, B3, C3, D3 and D4) are defined, based on the Kemler code (Danger Index code or GEVI code) of the substances carried (see Table 1.5). Data on the transport of hazardous substances may be gathered from information supplied about the Dutch railways (NS), the main operator in the Netherlands. By default, 33% of rail transport takes place during the day, and 67% of rail transport occurs at night.

Two railway types, high speed and low speed, are distinguished in respect of the difference in initial accident probability. The average initial accident probability for a rail car on an open track is $3.6 * 10^{-8}$ per rail car kilometre. The average number of rail cars involved in an accident depends on the speed of the train. Taking this aspect into account results in average accident probabilities of $2.2 * 10^{-8}$ for speeds below 40 km/h (low speed) and $4.5 * 10^{-8}$ for speeds exceeding 40 km/h (high speed) per rail car kilometre.

Three types of trains are distinguished in IPORBM; mixed trains, block trains and dedicated chlorine trains. For dedicated chlorine trains, which have only rail cars with chlorine, a fivefold lower initial accident probability is assumed due to the fact that these trains are subjected to extra stringent safety precautions in the Netherlands. Mixed trains are trains with both flammable gas (substance category A) rail cars and flammable liquids (substance category C3) rail cars. For mixed trains, the assumed BLEVE event probability for flammable gases is twice that for block trains, thus compensating for the increased fire hazard resulting from cars containing flammable liquids. Block trains (for flammable gas) are trains without any rail cars containing flammable liquids.

In IPORBM, default standard average accident frequencies are used, which depend on railway type and train type as described above. The average situation is defined as an open track with an average number of crossings (0.66 per kilometre) and points (0.27 per kilometre) and safeguarded with an ATB safety system. However, specific situations may be identified where the use of a specific frequency for a part of a route section is appropriate. The average accident frequency of $3.6 * 10^{-8}$ per rail car kilometre may be multiplied by a factor, which is given in Table 2.2 for some specific situations. No correction factors have yet been derived for the specific situation of trains passing through stations and shunting yards.

*Table 2.2 Factors for the multiplication of the average accident-frequency 3.6 * 10^{-8} per rail car kilometre for specific situations*

Specific situation	**Factor**
High speed (>40 km/h)	1.26
Low speed (<40 km/h)	0.62
ATB-new generation	0.9
No crossings and no points (/kilometre)	0.6
One -crossing, no point (/kilometre)	0.8
One point, no crossing (/kilometre)	1.5
A crossing and a point (/kilometre)	1.8
Hot box detection	0.8

Default ignition probabilities for flammable gases (A) and liquids (C3) are shown in Figure 2.4. In the case of a pool fire, the immediate and delayed ignition effects are assumed to be equal and the probabilities are added. The default values are recommended, although the default values for the ignition probabilities may be changed.

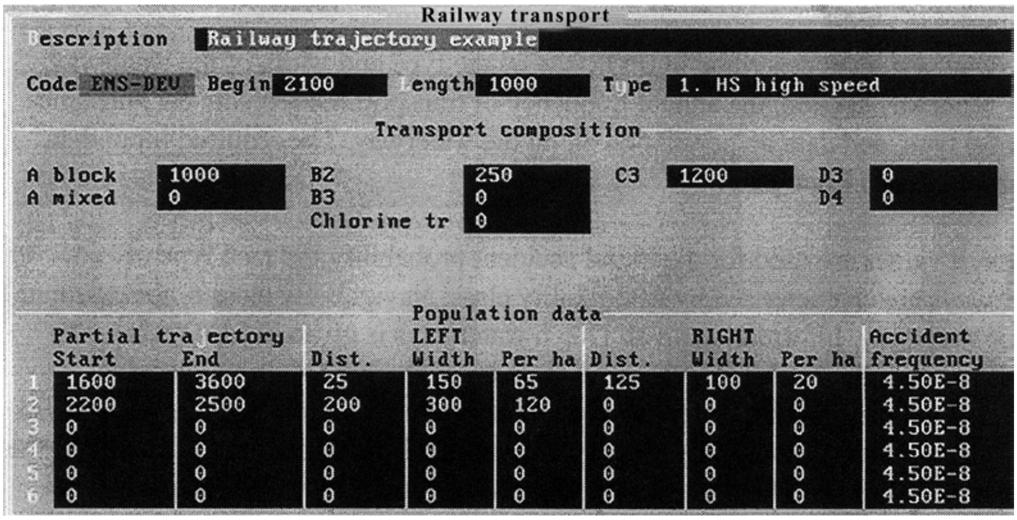

Figure 2.3 The railway modality main entry screen.

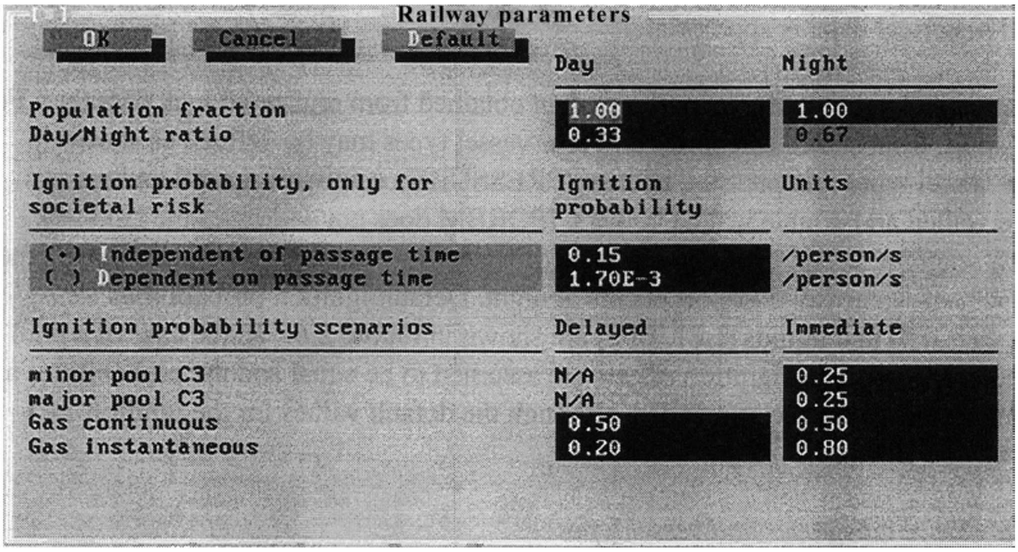

Figure 2.4 The Railway Parameters dialog box

2.5 Inland waterway

The inland waterway system is described in IPORBM by the type and width of the waterway, the length of the waterway section, the annual frequency of transport movements per substance category and vessel type, and data on population along the waterway. The required input data are shown in Figure 2.5 and Figure 2.6.

In IPORBM, default values are used for the initial accident probability for each type of waterway. Waterways are characterised by navigability class. Navigability class 6, for example, describes a major waterway. Information on all Dutch waterways is given in [AVV97a]. The navigability class of a number of Dutch waterways is given in chapter 1.4. Initial accident probabilities are defined per part of a waterway route section, and refer to accidents resulting in major damage to one or more vessels. The program then uses this information, together with the type of waterway and vessel specified, to calculate the probability of LOC. Accidents can be assumed to be distributed across the width of the waterway. In IPORBM the waterway is therefore divided into nine lanes of equal width, and for each lane a fraction of the accident frequency must be defined. The default initial accident frequencies used in IPORBM are indicative; they can only be used for a first rough approximation of risk levels. There is a wide spread in initial accident probabilities. Near manmade objects in the waterway (bridges, locks), or near crossings and narrow bends, the accident frequencies can increase by ten or even a hundred times. For these specific situations the use of a specific frequency, based on nautical judgement and historical data, is appropriate.

Data on the nature and volume of transport are often obtained from registered lock passages. For waterway transport, 8 substance categories and four vessel types may be defined as shown in Table 2.3. The vessel types are: pressure tankers (PRESSURE), semi-pressurised tankers (SEMI), single walled and double walled tankers. IPORBM does not addresses the risks associated with seagoing vessels. By default, 50% of waterway transport takes place during the daytime, and 50% of waterway transport occurs at night. Default ignition probabilities for flammable gases (GF3) and liquids (LF 1, LF2) are shown in Figure 2.6. In the case of a pool fire, the immediate and delayed ignition effects are assumed to be equal and the probabilities are added. The default values are recommended, although the default values for the ignition probabilities may be changed.

Table 2.3 Substance categories and vessel types

Main substance category	Subcategory	Vessel type
Flammable gas	GF3	Pressure
Toxic gas	GT3	Pressure
Toxic gas	GT3	Semi-pressurised
Flammable liquid	LF1	Single/double walled
Flammable liquid	LF2	Single/double walled
Toxic liquid	LT1	Single/double walled
Toxic liquid	LT2	Single/double walled
Toxic liquid	LT3	Single/double walled
Toxic liquid	LT4	Single/double walled

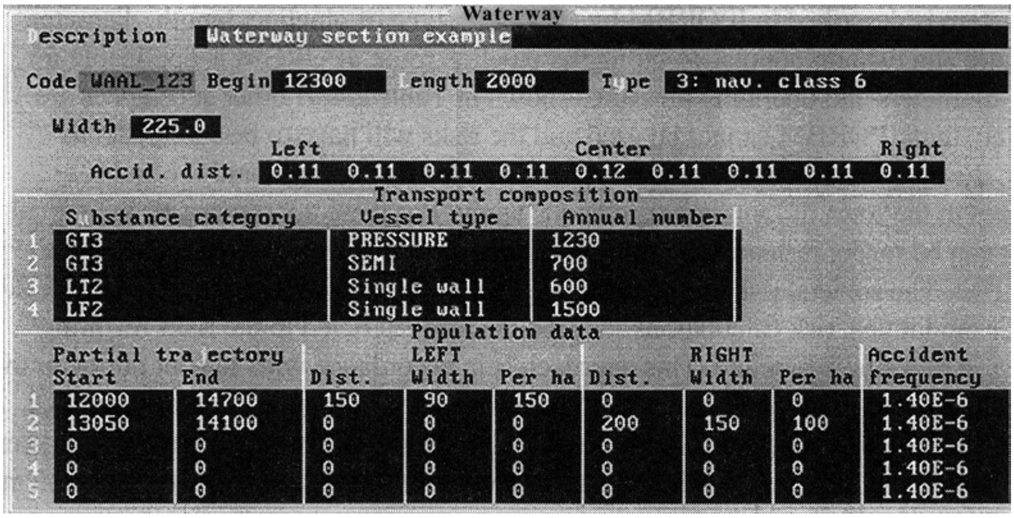

Figure 2.5 The waterway modality main entry screen

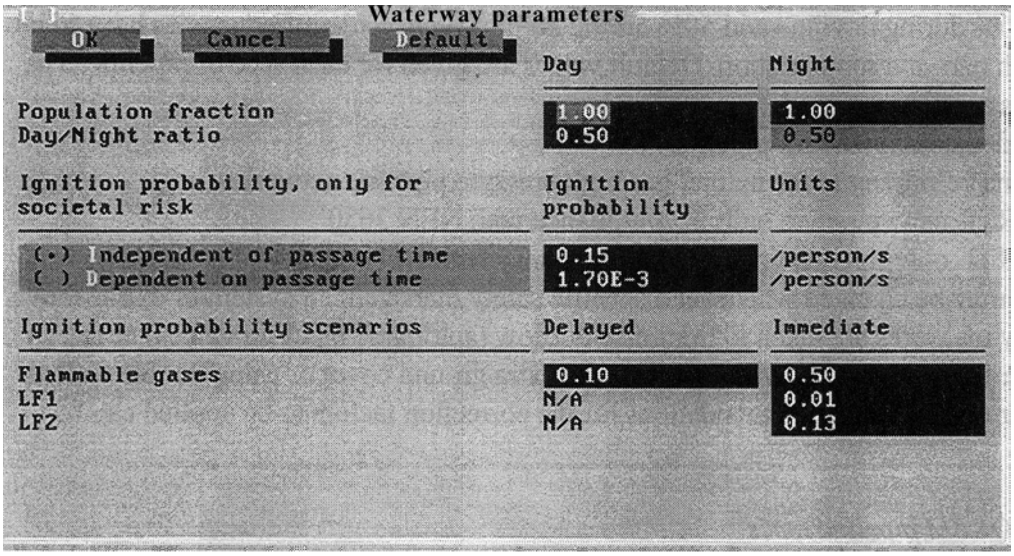

Figure 2.6 The Waterway Parameters dialog box

2.6 Pipeline

The pipeline system is described in IPORBM by substance, type of pipeline, length, diameter, operating pressure and data on population along the pipeline route. IPORBM is applicable for the substances, diameters and operating pressures shown in Table 2.4. If other substances are being transported, then IPORBM cannot be used and the risks will have to be calculated in another way. In the Netherlands, for several substances such as natural gas and K1 and K2 liquids, directives in the form of (zoning) regulations apply. For these substances no individual risk calculation can be made; instead, the required zoning distances shown in chapter 3.5 are given by IPORBM. The societal risk can be calculated for all substances mentioned in Table 2.4. Unlike the other modalities, risk calculations for pipelines are restricted to the risks resulting from the operation of a single pipeline. This approach is in accordance with current policy in the Netherlands. The required input data for IPORBM are visualised in Figure 2.7 and Figure 2.8. Default ignition probabilities for flammable gases and liquids are shown in Figure 2.8. The user may change the default values. In the individual risk calculation the assumption is made that any flammable gas released will always be ignited.

Information on the nature and mode of hazardous substance transport by pipeline can be obtained from the pipeline operator. It is assumed that pipeline transport takes place around the clock, that is 50% during daytime and 50% during night-time. Accident frequencies have to be entered for each part of a route section. Default values are given for each type of pipeline. The following types are distinguished:

- Pipeline on dedicated route for pipelines
- HTL: pipeline belonging to the natural gas high pressure pipeline network
- NEN 3650/RTL new: pipeline built in compliance with NEN 3650
- NEN 3650/RTL old: pipeline not built in compliance with NEN 3650

Default values may be changed whenever a specific safety management system or extra, above standard, safety measures are taken to minimise outflow (automatic block-in valves) or to protect the pipe from external interference, such as extra ground cover or using double walled pipes. However no specific recommendations for the correction factors to be applied can be given.

Table 2.4 IPORBM pipeline types

Substance category	Diameter [inches]	Operating pressure [bar]
Natural gas	2, 4, 6, 8, 10, 12, 14, 16, 18, 24, 30, 36, 42, 48	40, 60, 90
Ammonia	4, 6, 8	10, 14, 20
Chlorine	2, 3, 4	12 through 20
Ethylene (Ethene)	6, 8, 10	50, 75, 100
Ethylene oxide	6 through 10	5 through 10
K1	4, 6, 8, 10, 12	all pressures
K2	4, 6, 8, 10, 12, 14, 16, 18, 24, 30, 36	all pressures
Carbon monoxide	6, 8, 24	20, 30
Propane	6, 8, 10	50, 75, 100
Vinyl chloride	8, 10	50, 75, 100

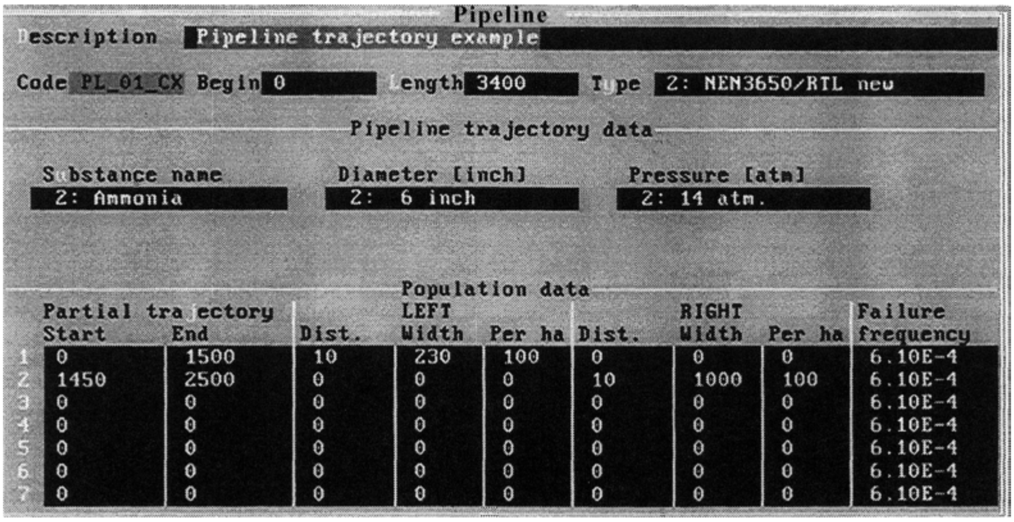

Figure 2.7 The pipeline modality main entry screen

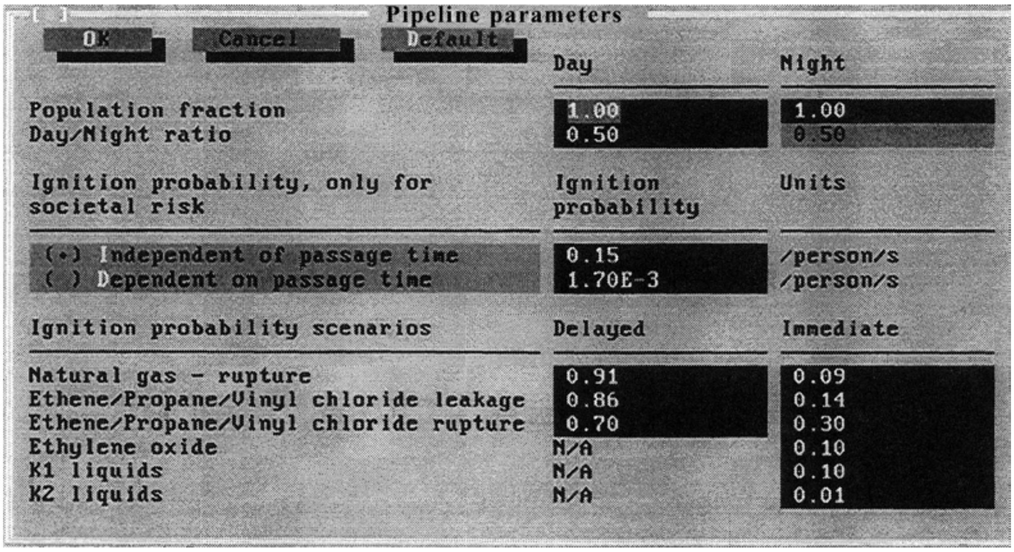

Figure 2.8 The Pipeline Parameters dialog box

3. DETAILED QRA

3.1 Introduction

This chapter gives an outline of a detailed QRA for the transport of dangerous substances in bulk based on current practice in the Netherlands. The loss of containment events (LOCs) that need to be included in the QRA are identified. The corresponding failure frequencies and the various events following a release, and their probabilities, are given. The modelling of the source term, dispersion, exposure and damage, and the calculation and presentation of the results, however, are not described in detail. Only the differences in modelling to that described for stationary installations at an establishment are highlighted.

The QRA rules given are general and to be applied to open situations, i.e. transport routes where no obstacles, such as tunnels and noise barriers, are present. Situations in which obstacles are present differ in several aspects from an open situation and therefore need to be considered on a case by case basis. In paragraph 3.2.5 these aspects are qualitatively described.

The basic data needed in conducting a QRA for a specific transportation route include the:

- Description of the transport streams (number of yearly loaded transport units per substance or category, during daytime and night-time)
- Description of the transport units (characteristic inventory)
- Description of the transport route (road type, obstacles present)
- Description of the number of accidents and degree of traffic in order to determine accident frequencies
- Description of the ignition sources
- Properties of transported (representative) substances
- Terrain classification of the surroundings of the transport route
- Meteorological data
- Population present in the surroundings of the transportation route

Guidelines for obtaining these data, recommended values and references to information sources are given in the next paragraphs and in chapter 4.

The level of detail of the QRA may be varied depending on whether or not location specific accident frequencies are used or specific hazardous substances or substance categories are included in the QRA. Preferably, location specific accident frequencies should be used in the QRA. Furthermore, on a case by case basis, the default release scenarios and events may be altered to meet the requirements of the specific situation. No general rules can be given. A method to identify transportation routes and specific locations where a QRA should be made is described in chapter 3. In chapter 2 IPORBM, a standardised but simplified calculation methodology for determining the risks involved in transporting hazardous substances, is described.

3.2 Road transport

3.2.1 Loss of containment events

The risks of the transport of dangerous substances by road are mainly determined by transport in bulk. The transport of small packages (drums, cylinders) and the transport of explosives and radioactive materials are hitherto not considered in a QRA. In the QRA a distinction is made between flammable and toxic substances (liquids and gases) transported in atmospheric and pressurised transport units (tankers and tank containers).

The typical inventory of an atmospheric tanker in the Netherlands is 23 metric tonnes. For a pressurised tanker with flammable gas a typical inventory is 20-25 metric tonnes and for a pressurised tanker with toxic gas a typical inventory of 16 metric tonnes may be assumed.

The LOCs for road transport are from [AVIV94, VeVoWeg96] and are given below.

Atmospheric tankers and tank containers:
- release of the complete inventory.
- release of 5 m^3 of the inventory.
- release of 0.5 m^3 of the inventory.

Pressurised tankers and tank containers:
- instantaneous release of the complete inventory of the transport unit.
- continuous release from a hole with an effective diameter of 50 mm (2 inches).

Notes:

1. No distinction has to be made in the QRA between tank containers and tankers.

2. Some substances such as hydrogen are transported in bulk as compressed gases or as refrigerated liquids. As the frequency of yearly transport movements is small compared to the frequency of transport movements of substances that determine the risks, these substances may in most cases of practical interest be omitted in the calculation.

3. LOCs for transport of explosives and radioactive materials differ from those given for flammable and toxic substances (liquids and gases). As explosives and radioactive materials are rarely transported, they need not be included in a QRA.

4. A release of 0.5 m^3 from an atmospheric transport unit will result in a small pool. In most cases of practical interest, such as open road situations, this LOC may be omitted in the calculation.

3.2.2 Accident and outflow frequency, events and event probabilities

The frequency of a hazardous event at a specific location on the transport route per transport unit per year, may be seen as the product of the initial accident frequency (per unit and km), the probability of a significant release (> 100 kg) given an accident for the specific transport unit and the probability of the hazardous event given a significant release.

The product of the initial accident frequency and the release probability is called the outflow frequency. Generic values (per transport unit km) for different road types are derived in [AVIV94] and given in Table 3.1 for pressurised and atmospheric transport units. The generic values are based on the number of known hazardous substance accidents with a known release in a certain period, and data on the transport of hazardous substances in the same period, estimated from transport statistics. The probability of significant release (> 100 kg) given an initial accident cannot be deduced directly, because the initial accident frequency of transport units with dangerous substances (including accidents with no release) as yet cannot be derived from general accident statistics.

Table 3.1 Outflow frequencies for different road types

Road Type	**Outflow frequency [/veh.km]**	
	Pressurised	**Atmospheric**
Motorway	$4.32 * 10^{-9}$	$8.38 * 10^{-9}$
Outside built-up area	$1.22 * 10^{-8}$	$2.77 * 10^{-8}$
Inside built-up area	$3.54 * 10^{-9}$	$1.24 * 10^{-8}$

In a detailed, location specific QRA it is current practice in the Netherlands to assume that the outflow frequency is a linear function of the injury accident frequency. The outflow frequency for a particular road section may then be determined by multiplying with the ratio of the location specific accident frequency to the average injury accident frequency for that road type. This procedure is outlined in section 4.3.2.

The hazardous events following a release to be considered in the QRA include:
- Toxic exposure
- BLEVE
- Jet fire
- Pool fire
- Flash fire
- Explosion

For the QRA default, immediate ignition probabilities are used as given in Table 3.2. Delayed ignition in Societal Risk calculations should be modelled as a function of the distribution of ignition sources (detailed QRA for existing/planned situation). When the specific locations of ignition sources are unknown the values from Table 3.2 may be used instead (QRA for a generic situation). Delayed ignition in an Individual Risk calculation should be modelled to give the maximum effects. Ignition at maximum cloud area should be assumed.

Table 3.2 Ignition probability

Substance category	**Ignition probability**	
	Immediate	**Delayed**
Flammable liquid, category LF2	0.065	0.065
Flammable liquid, category LF1	0.0043	-
Flammable Gases	0.8	0.2

Events and default event probabilities for flammable substances are given in Figure 3.1 and Figure 3.2. The events and effects following immediate and delayed ignition of a release of flammable liquids category LF2 are almost the same, so the probabilities of delayed ignition is added to the probability of immediate ignition as shown in Figure 3.2. Delayed ignition of a release of flammable liquids category LF1 may be omitted in the calculation. By definition, LF1 substances have no flammable cloud beyond the liquid pool. For toxic gases and toxic liquids all relevant releases lead to a toxic exposure.

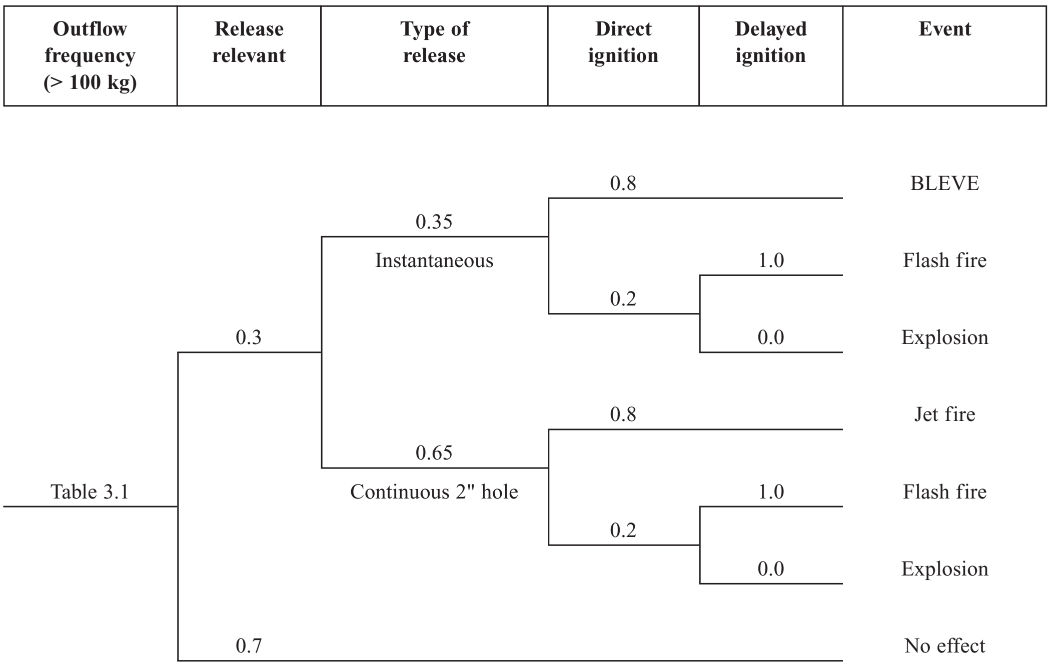

Figure 3.1 Event tree pressurised flammable gas

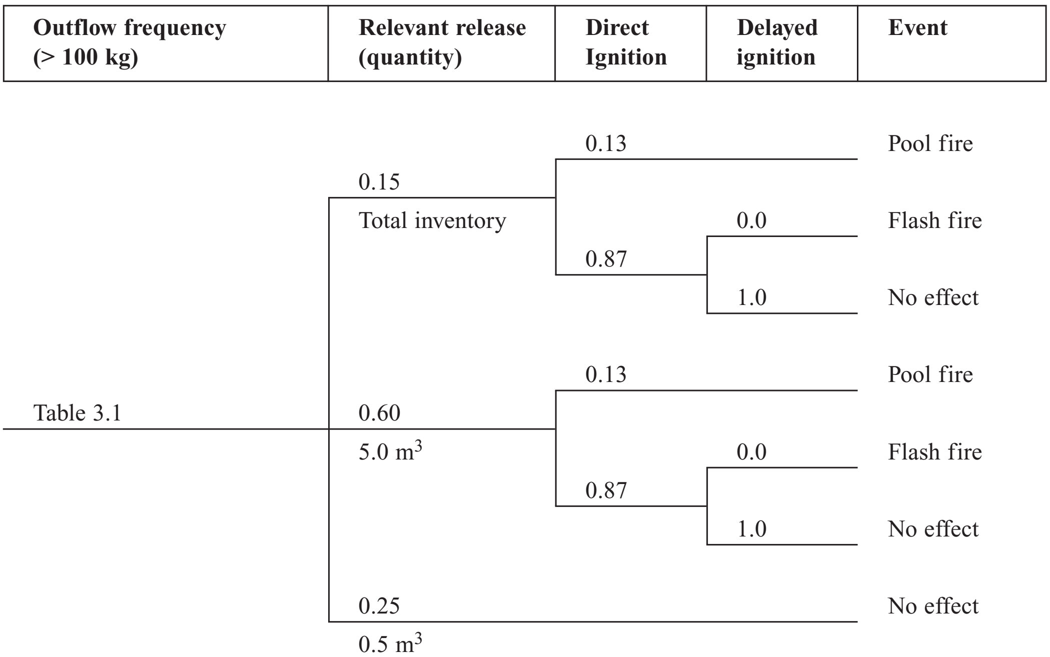

Figure 3.2 Event tree atmospheric, flammable liquid LF2

Notes:

1. In a fire, unburned toxic substances and toxic combustion products can be released to the environment. In the case of open fires (open road situations), plume rise, due to the high temperature of the cloud, is assumed to occur immediately and no lethal effects are expected. Exposure to unburned toxic substances and toxic combustion products do not have to be considered in the QRA.

2. The release of the internal energy of a ruptured, pressurised transport unit can give rise to blast waves and high velocity vessel fragments. These effects do not have to be considered in the QRA for an open road situation.

3. Substances that are both toxic and flammable should in principle be modelled using toxic properties as long as the cloud is not ignited, and with flammable properties as soon as the cloud ignites. However, this approach is currently too complicated for the models used. The LOC is therefore split into two independent events, namely, a pure toxic and a pure flammable event (see section 4.7.3).

4. Following the delayed ignition of a vapour cloud, depending on obstruction, either a flash fire or blast overpressures (explosion) result. In open road situations the vapour cloud is unconfined. In the QRA only the occurrence of flash fires need to be included, although in densely populated or confined areas the occurrence of an explosion cannot totally be excluded.

3.2.3 Modelling source term, dispersion, exposure and damage

After defining the loss of containment events and the resulting hazardous events, the source term and the dispersion in the environment will have to be calculated, and the exposure and damage determined. As the modelling in most cases does not differ from that described for stationary installations at an establishment, only the specific aspects and differences are highlighted in this chapter.

Notes:

1. The continuous release from a pressurised transport unit is modelled as a hole in the vessel wall with a sharp orifice. The value of the discharge coefficient should be set at Cd=0.62. Two-phase outflow should be assumed. The release duration is to be determined using the transport unit inventory and the mass flow rate. In the QRA calculation, the release duration is limited to a maximum of 30 minutes
2. The direction of the continuous outflow from a pressurised transport unit is set as horizontal, parallel to the wind, because in an accident situation no specific information is available. In the case of direct ignition of a flammable gas, assume that the jet is unobstructed (free jet). In all other cases (delayed ignition flammable gas, continuous outflow of liquefied, compressed toxic gases) obstructed outflow should be assumed. The obstructed outflow should be modelled as a jet with the impulse reduced by a factor of 4 and with dimensions determined by the outflow conditions.
3. For an instantaneous release of liquefied compressed gases, the mass in the vapour cloud depends on the adiabatic flash fraction, y, and is given by the relations in Table 3.3.

Table 3.3 Mass in vapour cloud following an instantaneous release

adiabatic flash fraction, χ	Mass in vapour cloud (fraction of the total inventory of the transport unit)
$\chi < 0.1$ $0.1 \leq \chi < 0.36$ $\chi \geq 0.36$	$2 * \chi$ $* \chi$ -0.028) / 0.26 1

4. lt is assumed that the direct ignition of an instantaneous release of liquefied, compressed flammable gas will result in a BLEVE. It has to be assumed that the total inventory of the transport unit takes part in the BLEVE.

5. The dimensions of the pool formed, following a release of liquid from an atmospheric transport unit, are determined by a number factors: the discharge rate, the total volume of the release, the roughness of the road and soil, the inclination of the surface and the possible discharge into a sewer. As these factors are in most cases unknown, and no information is available, a fixed pool may be assumed in the QRA. lt is recommended for a release of the total inventory of a transport unit to assume a pool size of 1200 m^2 , and for a release of 5 m^3 to assume a pool size of 300 m^2 [VeVoWeg96].

6. The meteorological data to be used in a QRA is described in section 4.10. Data from a representative meteorological station for the transport route under consideration should be used. If necessary, data from different stations should be used for different road sections.

7. A representative value for the aerodynamic roughness length z0 for the terrain surrounding the transport route, as described in section 4.6.2, should be used. If necessary, different values should be used for different road sections.

8. Chemical processes, and the wet and dry deposition processes, do not have to be considered in the modelling of the vapour cloud dispersion.

9. Exposure and damage should be modelled as described in chapter 5 of [RIVM99]. For BLEVEs, a maximum exposure time of 20 seconds in built-up areas as well is recommended.

10. The population present in the surroundings of a transport route should be surveyed according to the rules outlined in section 5.3. The survey of the population present within 300 meters should be more detailed than at larger distances from the transport route. The risks along a transport route are dominated by the transport of flammable liquids and gases and the effective distances of the significant scenarios are less than or comparable to 300 metres.

3.2.4 Calculation and presentation of results

The results of a QRA are the Individual Risk and the Societal Risk and have to be presented clearly as described in chapter 6 of [RIVM99]. A widely used method for the calculation of risks is described in section 6. According to current regulations, the Societal Risk has to be calculated and presented per kilometre of transport route.

Notes:

1. The size of the calculation grid should be small enough not to influence the calculation results. The size of the grid cell should not be larger than 25 x 25 metres, as the risks along a transport route are dominated by the transport of flammable liquids and gases and the effective distances of the significant scenarios are less than or comparable to 300 metres. At distances larger than 300 metres, a larger grid cell may be used. Consequently, the survey of the population present within 300 metres should be more detailed than at larger distances from the transport route. It should be ensured that the distance of the population from the transport route is correctly represented.

2. Accident locations have to be selected at regular distances, and beyond the beginning and end of the road section under consideration, to produce a smooth risk contour. There should be enough locations to ensure that the risk contour does not change substantially when the number of accident locations is increased.

3. In the calculation of the Societal Risk, the choice of the beginning and end of the sections for which the results are presented may be arbitrarily specified beforehand. However, sections should be chosen in such a way that the Societal Risk is maximised.

4. As well as the presentation of the Individual Risk and the Societal Risk, other results can be presented which will give a picture of the risks. Useful presentations include graphs of the

probability of death along the centre line as a function of distance for the dominant LOCs. Also, those road sections with the highest risks or the road sections and locations which do not comply with the risk criteria may be highlighted. The contribution of the different substances or substance categories, or the contribution of the transport during day or night to the overall risks may be specified.

3.2.5 Obstacles

A specific road section may be (partly) covered or a tunnel may be present. Also, obstacles such as (noise) barriers may be present. Specific road sections may be elevated (viaduct, bridge) or located below ground level. The presence of these obstacles and their influence on the risks should, in principle at least, be qualitatively incorporated in the QRA.

These obstacles, depending of the type of obstacle and the hazardous substance involved, influence the calculation of the risks in several ways:

- The initial accident frequencies may differ from those on open road sections where obstacles are not present. The probability of a BLEVE in a tunnel may be larger than in open road situations because of the higher temperatures in case of a fire occurring in a tunnel.
- The probability of a large release in tunnels, and the dimensions of the liquid pool formed, differ from those in open road situations or in cases where other barriers are present or the road is elevated.
- The evaporation from liquid pools, and the dispersion of the hazardous vapour cloud formed, are influenced by the presence of barriers. The ventilation and presence of vehicles in tunnels influences the evaporation.
- The release of toxic combustion products and heat resulting from fires in tunnels and enclosures must be considered.
- The formation of the vapour cloud following a release and flash of liquefied, compressed gas is restricted by the enclosure. Heat transfer from tunnel and road surfaces however may enhance the evaporation.
- In enclosed situations the occurrence of confined explosion is possible. Also in tunnels, due to the release of internal energy, blast waves and pressure loads may result which lead to failure of the enclosure. Depending on the hazardous substance, the release scenario involved, and the strength and openness of the enclosure (tunnel, covering) these explosions may or may not lead to the failure of the enclosure, the formation and dispersal of fragments. Consequently hazardous effects may occur at the ends of the enclosure or along the enclosure.
- Due to the presence of obstacles the heat radiation to the surroundings may be attenuated.

The influence on the risks of the aspects mentioned above should be considered on a case by case basis. No general rules can be given. There is yet no general consensus on how these effects should be incorporated into a QRA. A preliminary model has been developed in the Netherlands in the project ABIETO-Aanzet tot een Berekeningsmethodiek voor In- en Extern risico bij Tunnels/Overkappingen (Initiative for a calculation method for internal and external risk at tunnels/covered areas). In the commonly used integrated software packages the aspects mentioned above can only be approximately addressed. Calculations with complex computer codes (CFD calculations) or experimental results are needed for a more reliable quantitative determination.

3.3 Rail transport

3.3.1 Introduction

This chapter gives an outline of a detailed QRA for the rail transportation of dangerous substances in bulk, in shunting yards, and in private sidings. The loss of containment events (LOCs) that need to be included in the QRA are identified. The corresponding failure frequencies and the various events following a release, and their probabilities, are given. The modelling of the source term, dispersion, exposure and damage and the calculation and presentation of the results is not described in detail. Only the differences in modelling as compared with stationary installations are highlighted.

The QRA rules are general and to be applied to railways, shunting yards and private sidings. The basic data for a QRA are:

- description of the transport streams (number of yearly loaded tank cars per substance or category, during daytime and night-time);
- description of the transport units (characteristic inventory);
- description of the transport route;
- description of the shunting yard or the private siding;
- description of the activities on the shunting yard or the private siding;
- accident frequencies;
- description of the ignition sources;
- properties of transported (example) substances;
- terrain classification of the surroundings of the transport route;
- meteorological data;
- population distribution in the surroundings of the transportation route, the shunting yard or the private siding.

Guidelines for obtaining these data, recommended values and references to information sources are given in paragraph 4.4.

3.3.2 Loss of containment events

The risk of the rail transportation of dangerous substances is determined by the bulk transport of flammable gas (A), toxic gas (B2 en B3), toxic liquid (D3 and D4) and flammable liquid (C3). All other substances are not relevant and do not have to be considered.

The LOCs for rail transportation are defined [SAVE95, SAVE95a]. The LOC’s are

- leakage from a 3" hole in the tank car;
- rupture of the tank car.

In this chapter a distinction will be made between accidents on a railway (outside shunting yards and private sidings) and at shunting yards or private sidings. Although the LOCs are identical for both situations, the appropriate LOC frequencies are different. Furthermore, distinction has to be made between atmospheric and pressurised rail tank cars.

Notes:

1. LOCs for explosives and radioactive material will differ from the LOCs for other dangerous substances. These transported substances are not normally included in the QRA as the transport frequency is low and there will therefore be no measurable influence on the risk level.

2. LOCs for small packages like drums and cylinders will be different to LOCs for bulk transport. These transport movements are excluded from the QRA if bulk transport takes place. This is because of their (too) little contribution to risk.

3.3.3 Accident and outflow frequency, events and event probabilities

For the definition of accident scenarios used to determine the accident frequency, distinction has to be made between private siding, shunting yards and railways.

3.3.3.1 Private siding

A private siding is a branch of the railway for the delivery of goods at a kind of terminal. Its characteristics are:
- the sets of points are manually operated;
- the maximum speed is 30 km/hr;
- level crossings with roads;
- not equipped with signs.

The accident frequencies have been determined [SAVE95a]. A distinction is made between the shunting yard part of the private siding and the railway part of the private siding. The frequencies are:
$1.1 * 10^{-6}$ per car per km for the railway part;
$8.4 * 10^{-7}$ per car for the shunting yard part.
For the latter, the accident locations are spread over the shunting yard part.
The outflow probability for atmospheric and for pressurised tank cars are given in Table 3.4:

Table 3.4 Outflow probability for atmospheric and pressurised tank cars

Scenario	atm. tank car	pressurised tank car
Collision	0.1	0.01
One car accident	0.1	0

3.3.3.2 Shunting yards

For shunting yards eight different scenarios are identified. Whether or not a scenario can take place depends on the shunting process. The full list of accident scenarios is:
sc. 1: a train collision upon arrival at or departure from a shunting yard;
sc. 2: a collision between an arriving/departing train and a set of wagons;

sc. 3: a collision between a set of wagons and a train that is shunted or formed;
sc. 4: a collision while changing locomotives;
sc. 5: an accident involving one tank car only;
sc. 6: a shunting accident;
sc. 7: intrinsic failure of a tank car;
sc. 8: a BLEVE of a tank car due to a leaking flammable liquid car nearby.

The accident frequencies are given in table 3.5 for atmospheric and pressurised tank cars. The probability of an outflow as a consequence of the accident is added to this table. This probability differs per type of tank car and per scenario.

Table3.5 Accident frequency and outflow probability for a shunting yard

Scenario		Accident frequency	Probability outflow	
			atm. tank car	Press. tank car
1.	Arrival/departure			
	. 'ATP' present	$5.5 * 10^{-7}$ per train	0.1	0.01
	. no 'ATP' present	$5.5 * 10^{-6}$ per train	0.1	0.01
2.	Collision with set of wagons	$2.12 * 10^{-5}$ per train	0.1	0.01
3.	Shunting/forming	$2.12 * 10^{-5}$ per train	0.1	0.01
4.	Changing locomotives	$1.0 * 10^{-6}$ per train	0.05	0.005
5.	One car accident	$2.75 * 10^{-5}$ per train	0.1	0
6.	Shunting accident	$1.76 * 10^{-5}$ per car	0.1	0.01
7.	Intrinsic failure	$5.0 * 10^{-7}$ per car.year	1	1
8.	BLEVE	Formula (note 4)	0	1

ATP: Automatic Train Protection

Notes:

1. The frequency of scenario 7 has additionally to be multiplied with the fraction of time that the car is present (per year).

2. The BLEVE frequency f on a shunting yard is calculated according to:

$$f = fo \cdot N \cdot n \cdot (Ap/A_{tot}) \cdot (t/12) \cdot (T/365) \cdot R$$

with
f : BLEVE frequency per year

fo	:	frequency of a major fire (= 3.1 * 10^{-7} per flammable liquid car)
N	:	number of flammable liquid cars per year.
n	:	number of pressurised tank cars per train.
Ap	:	area of flammable liquid pool (= 600 m^2)
A_{tot}	:	area of shunting yard (m^2)
t	:	hours that a pressurised car is present per day (is divided by 12 for the hours/day. If day plus night is used, then the denominator should be 24.)
T	:	number of trains with pressurised cars per year (is divided by 365 which is the number of days in a year)
R	:	repression factor (= 0.1)

This formula is based on the assumption that pressurised and atmospheric cars are present at the same time. If not, the BLEVE frequency equals zero.

Multiplication of the accident frequency with the outflow probability will give the outflow frequency. As only 10% of the outflows are relevant for external risks the outflow frequency has to be multiplied with 0.1. This does not apply to scenarios 7 and 8 as they represent instantaneous sources.

This approach results in outflow frequencies per train or per car. These frequencies have to be multiplied by the actual number of trains and cars that are handled per year in the shunting yard. lt was agreed [SAVE97] not to use the actual number of trains but to put these numbers into categories. The translation is carried out as presented in table 3.6.

Table 3.6 Categorisation of frequency per year of cars or trains

Actual frequency range per year	Frequency per year for the calculation
1 - 12	0
13 - 50	50
51 - 100	100
101 - 200	200
201 - 400	400
401 - 800	800
801 - 1600	1600
etc.	etc.

When trains consist only of cars with the same dangerous substance, no further correction is necessary.

If the train has a mixed composition and the frequency is given per train, then the LOC frequency has to be multiplied by the fraction of cars in the train with the dangerous substance under consideration.

An outflow (larger than 100 kg) may lead to a continuous source or an instantaneous source (excluding scenarios 7 and 8). The probability of a continuous source is 0.6 and that of an instantaneous source is 0.4.

In cases of flammable gas or liquid, an immediate ignition is possible. This probability is set at 0.8.

The locations of possible accidents are equally spread over that part of the shunting yard where the activity under consideration actually takes place.

3.3.3.3 Railways

The generic accident frequency for a rail car on railways outside the shunting yard is $3.6 * 10^{-8}$ per car kilometre [SAVE95]. If it is known that the train speed is more than 40 km/hr, then this frequency has to be corrected by multiplying by 1.26. If the speed is lower than 40 km/hr then the correction factor is 0.62.

If there is a set of points on the railway, the accident frequency is increased by $3.3 * 10^{-8}$ per car km.
For a level crossing the addition is $0.8 * 10^{-8}$ per car km.
So:
For 1 km track with 1 set of points : $6.9\ 10^{-8}$ per car
For 1 km track with 1 level crossing : $4.4\ 10^{-8}$ per car.

For dedicated chlorine trains in the Netherlands the accident frequency is multiplied by 0.2 because of extensive safety measures.

Given an accident occurs, probabilities for a release of more than 100 kg have been set. A distinction is made between sections where train speeds are allowed to be more than 40 km/hr and where they must be less than 40 km/hr.

Table 3.7 presents the results.

Table 3.7 Probability of outflow (> 100 kg) given an accident

Allowed	Probability of outflow (> 100 kg)	
Train speed	Atmospheric tank cars	Pressurised tank cars
< 40 km/hr	$7.9 * 10^{-2}$	$7.9 * 10^{-4}$
> 40 km/hr	$5.6 * 10^{-1}$	$2.8 * 10^{-3}$

Given a relevant outflow, the probability of an instantaneous source is 0.4 and of a continuous source is 0.6.

For flammable gases the probability of direct ignition is set at 0.8 for an instantaneous source and 0.5 for a continuous source. For flammable liquids the probability is 0.5.

If there are cars with flammable liquid in a train of mixed composition, the BLEVE risk for cars with flammable or toxic gas increases. The reason for this is the possibility of a burning pool under the car. This risk increase is incorporated as follows:

. if a train consists of cars with flammable gas and of cars with flammable liquid then the BLEVE frequency is multiplied with (N + l),
  where N is the number of flammable liquid cars per train;
. if a train consists of cars with toxic gas and of cars with flammable liquids, the frequency of an instantaneous release is multiplied by (0.8 N + l), where N is the number of flammable liquid cars per train.

If a train consists only of cars with a liquefied flammable gas then the BLEVE frequency is not increased. [SAVE95] shows that the extra contribution is negligible.

3.3.4 Modelling source term, dispersion, exposure and damage

After defining the loss of containment events and the resulting hazardous events, the source term and the dispersion in the environment will have to be calculated and the exposure and damage has to be determined. As the modelling in most cases does not differ from those described for stationary installations at establishments (chapter 6 of [RIVM99]), only the specific aspects and differences are highlighted in this chapter.

Notes:

1. For atmospheric tank cars, outflow is not calculated. lt is agreed that a continuous source results in a pool of 300 m^2 and an instantaneous source in a pool of 600 m^2. The source term for dispersion is equal to the calculated evaporation rate. The assumptions for the evaporation calculations are that the depth of the gravel layer is 0.15 m and the gravel diameter is 1 CFD.
2. For pressurised liquefied gases the double flash percentage gives the vapour source in cases of an instantaneous source. The fluid, not flashed, will evaporate according to the description given in note 1. The amount that evaporates during one minute should be added to the source term. For leakage, full evaporation is assumed.
3. The inventory of pressurised tank car is set at:
   - flammable gas : 48 tonnes
   - toxic gas : 50 tonnes

   For the future (2010) larger inventories are expected. The flammable gas tank car may contain 54 tonnes, chlorine tank cars 60 tonnes and ammonia tank cars 58 tonnes.
4. A direct ignition of an instantaneous release of flammable gas results in a BLEVE of the total inventory.
5. A direct ignition of a continuous release of flammable gas results in a jet fire comprising the total outflow rate.
6. The continuous outflow is calculated as a flow out of a 3" hole with a contraction coefficient of 0.67.
7. The meteorological data to be used in a QRA is described in section 4.10. Data from a representative meteorological station for the transport route or the shunting yard under consideration should be used. If necessary, data from different stations should be used.

8. A representative value for the aerodynamic roughness length Zo for the terrain surrounding the transport route or the shunting yard as described in section 4.6.2 should be used. If necessary, different values should be used for different sections. Default value z_o=1.0 metre.
9. Chemical processes and the wet and dry deposition processes do not have to be considered in the modelling of the vapour cloud dispersion.
10. Exposure and damage should be modelled as described in chapter 5.
11. The population present in the surroundings of a transport route or the shunting yard should be surveyed according to the rules outlined in section 5.3.

3.3.5 Calculation and presentation of results

The results of a QRA are the Individual Risk Contours and the Societal Risk Graphs. A widely used method for the calculation and presentation of risks is described in chapter 6 of [RIVM99]. According to current regulations the Societal Risk has to be calculated and presented per kilometre of transport route. For shunting yards this does not of course apply.

Notes:

1. The size of the calculation grid should be small enough not to influence the calculation results. The size of the grid cell should not be larger than 25 metres as the risks along a transport route are dominated by the transport of flammable liquids and gases and the effective distances of the significant scenarios are less than or comparable to 300 metres. At distances greater than 300 metres, a larger grid cell may be used.
2. Accident locations on the transport route have to be selected at regular distances and beyond the beginning and end of the section under consideration to produce a smooth risk contour. There should be enough locations to ensure that the risk contour does not change substantially when the number of accident locations is increased.
3. In the calculation of the Societal Risk for transport routes the choice of the beginning and end of the sections for which the results are presented may be arbitrarily set beforehand. However, sections should be chosen in such a way that the Societal Risk is maximised.

3.4 Inland waterway transport

3.4.1 Introduction

This chapter describes the QRA for the transport of dangerous substances in bulk by inland waterways. The QRA rules given are general and applicable to main inland waterways of normal nautical complexity. Situations in which specific nautical circumstances occur need specific consideration, such as passing through locks or at harbours.

The basic data needed in conducting a QRA for a specific inland waterway include the:
- Description of the inland waterway (navigability class, navigable width and overall width)
- Description of the transport streams (annual frequency of loaded transport units per substance)
- Description of the number of accidents and amount of traffic in order to determine accident frequencies
- Description of the transport units (characteristic inventory)
- Description of the ignition sources

- Properties of transported substances
- Terrain classification of the surroundings of the waterway
- Meteorological data
- Population present in the surroundings of the waterway

Guidelines for obtaining these data, recommended values and references to information sources or previous chapters are given in this chapter and chapter 4.

3.4.2 Loss of containment events

The risks of the transport of dangerous substances by inland waterways are determined by numerous factors, the most important of which are:

- type of containment of the substance e.g. type of ship or tank
- substance properties e.g. chemical, physical, toxicological
- waterway characteristics e.g. traffic density and composition, curvature, navigable width, current

As for all transport units the LOCs for external impact e.g. collisions with other ships or objects, dominate the risks of *moving* vessels. In a harbour this may of course be different. A check on the contribution of other LOCs, such as intrinsic failure, may then be appropriate.

Type of containment

QRAs of inland waterways are limited to the transport of dangerous liquids and gases in *bulk*. Solids are not considered due to the minor effect they have on the *external* risk. Transport in containers is not considered because of the limited quantity of a packing unit and the reduced probability of outflow compared to other vessels.

The following vessel types are considered:

- Single hull vessel
- Double hull vessel (transport at room temperature or refrigerated transport)
- Gas tanker

Typical loading capacities of vessels range from 300 up to 2000 tonnes. Individual tanks may contain up to 200 m^3 of inventory.

Properties of substances

QRAs of inland waterways are limited to the transport of dangerous *liquids* and *gases*. Solids are not considered though they may present an environmental problem or a problem of occupational safety. The transport of explosives and radioactive materials on inland waterways is extremely rare and is hitherto not considered in a QRA.

Waterway characteristics

Waterway characteristics are a part of the QRA. The level of detail depends on the required thoroughness of the analysis. At least the following needs to be known:

- overall width of the waterway
- navigable width of the waterway
- the distribution of the traffic on it

The LOCs for inland waterway transport are from [V&W89, SAVE88, AEA95] and given below.

Table 3.8 LOC's for external impact (traffic incidents) of moving vessels

Vessel type	**Outflow**	**Volume**	**Duration (min)**
Single hull	continuous minor	30 m^3 from 150 m^3 tank	30
	continuous major	75 m^3 from 150 m^3 tank	30
Double hull or refrigerated	continuous minor continuous major	20 m^3 from 150 m^3 tank 75 m^3 from 150 m^3 tank	30 30
Gas tanker [1])	continuous minor	hole diameter 3" in 180 m^3 tank	30
	continuous major	hole diameter 6" in 180 m^3 tank	30

[1]) Temperature is an important parameter in calculating the outflow rate. Pressurised transport at a decreased temperature (but not totally refrigerated) is sometimes indicated as “semi-gas”. The same LOCs are applicable (see also note 1 below).

Notes:

1. The scenario considered is the rupture of a pipe connected to the tank following a dislocation of the tank due to the impact. The largest pipe diameter connected to the liquid phase is 6". Outflow should be calculated as two phase flow. The location of the rupture is conservatively taken as close to the pressure vessel wall. The release is modelled as a hole with a sharp orifice (C_d=0.62). The direction of outflow is set as horizontal, parallel to the wind. The temperature (and saturation pressure) of the transported medium should be taken into account. For example, for the transport of ammonia it is often taken to be 5°C. Sometimes this state is referred to as a separate vessel type called “semi-pressurised” or “semi-gas tanker”.
2. The typology of vessels is relatively approximate. Since the introduction of the LOCs in the late eighties, ship-technology and classification demands have developed. The ADNR [ADNR], the international treaty on the transport of dangerous substances in the river Rhine area, lays down the construction demands on the following vessel types:
   - N-vessels (Rn. 331.000)
   - C-vessels (Rn. 321.000)
   - G-vessels (Rn. 311.000)
   - Dry bulk single hull vessels (Rn 110.000)
   - Dry bulk double hull vessels (Rn. 110.288)

   The last two vessel types are not considered in the QRA. G-vessels are gas tankers, C-vessels are double hull vessels. N-vessels are considered as “single hull vessels”. Some conservatism is built in here as the category N-vessels contains pure single hull vessels as well as single hull vessels with independent tanks.
   The default link between substance categories and ship types is given in Table 3.9.

Table 3.9 Relation between substance category and ship type

Substance category	**Ship type**
LF1, LF2	Single hull
LT1, LT2	Double hull
GF, GT	Gas tanker

The minimum allowable tank ship type for a specific substance is laid down in addendum 4 of appendix B2 of the ADNR.

If it happens that substances are transported more safely than the minimum, e.g. a C-type vessel is used where a N-type is in the list, this may be taken into account in a detailed QRA. For substance categories where N- as well as C-vessels are possible, e.g. the categories of the flammable liquids, the list of substances of the ADNR may be conservatively used for an estimation of the ratio single hull/double hull.

3. The LOCs of Table 3.8 are applicable in cases where the fraction of seagoing vessels is below 10%. For collisions between seagoing vessels, and between seagoing vessels and inland vessels, different LOCs should be considered [PROT98].

3.4.3 Accident frequency and outflow probabilities

The frequency of a hazardous event at a specific location on the transport route per transport unit per year can be represented as the product of: an initial accident frequency (per unit km), the probability of significant release given an accident for the specific transport unit, and the probability of the hazardous event given a release.

Initial accident frequency

The initial accident frequency is the frequency of serious damage to a vessel per unit distance, (vessel kilometre). The basic data needed to estimate the accident frequency are described in chapter 4.5. Typical for N-vessels are values between 10^{-4} and 10^{-7} per vessel kilometre per year [AVIV93].

The initial accident frequency is strongly dependent on local factors. A generic approach to the QRA should therefore be conducted with care.

In Table 3.10 from [IPORBM], default values for the initial accident probability are given. As stated before, these frequencies should be used with the utmost care. Whenever possible frequencies should be derived from local data. The method is described in chapter 4.5.
Local accident frequencies for a number of locations along main waterways in the Netherlands may be found in [AVIV93]. The navigability class for the main inland waterways in the Netherlands is given in Table 3.11.

Table 3.10 Default values for the initial accident frequency as a function of navigability class

Navigability class (CEMT)	Initial accident frequency (/vessel km)
4	$6.7*10^{-7}$
5	$7.5*10^{-7}$
6	$1.4*10^{-6}$

Table 3.11 Navigability-class of some Dutch inland waterways

Waterway	CEMT class	Waterway	CEMT class
Eemskanaal	5	Waal	6
v Starckenborghkanaal	5	Beneden Merwede	6
Prinses Margrietkanaal	5	Noord	6
IJssel	5	Hollandsch Diep	6
Nederrijn	5	Schelde-Rijnkanaal	6
Lek	5	Maas	5
Amsterdam-Rijnkanaal	6	Julianakanaal	5
Nieuwe Maas	6	Kanaal Gent-Terneuzen	6
Oude Maas	6	Hollandsche IJssel	5
Oude Rijn/Gouwe	4		

Probability of release
The probability of release given serious damage (or, for G-vessels, more severe damage) is taken from [V&W89] and given in Table 3.12.

Table 3.12 Probability of release given serious damage

Vessel type	Outflow	Probability given serious damage
Single hull	Continuous minor	0,2
	Continuous major	0,1
Double hull or refrigerated	Continuous minor	0,006
	Continuous major	0,0015
Gas tanker (irrespective of, transported substance temperature)	Continuous minor	0.025
	Continuous major	0.00012

Probability of hazardous event
The events to be considered in the QRA are
- Toxic exposure
- Pool fire

- Jet fire
- Flash fire

For the QRA, default immediate ignition probabilities are used as given in Table 3.13. In Societal Risk calculations delayed ignition should be modelled as a function of the distribution of ignition sources (detailed QRA for existing/planned situation). When the specific locations of ignition sources are unknown the values from Table 3.13 may be used instead (QRA for a generic situation). Delayed ignition in a Individual Risk calculation should be modelled to give the maximum effects. Ignition at maximum cloud area should be assumed.

Table 3.13 Ignition probability

Substance	**Ignition probability**	
	Immediate	**Delayed**
Flammable liquid, category LF2	0.065	0.065
Flammable liquid, category LF1	0.01	-
Flammable Gases	0.5	0.1

Notes:

1. As already stated, initial frequencies may vary widely due to local factors. The question is how to decide whether a specific location "deserves" its own accident frequency. Two factors are relevant to making this decision:
   - Nautical judgement;
   - Historical data.

   Review of the distribution of locations of accidents along the waterway may indicate possible concentration points. A nautical expert judges whether (and which) specific local factors are present that may increase the accident frequency. If so, the accidents (or some of them) are considered specific for that location. If not ("the accidents might as well have happened anywhere else along the waterway") the accidents are considered representative for the total length of waterway being studied. More detail on the retrieval of accident frequencies from accident data is given in chapter 4.5.
2. Nautical judgement is necessary in evaluating the effect of local measures on the accident frequency. Local measures are, for example, restrictions in overtaking, moving speed, anchoring. A traffic and accident model has been developed [MSCN95] to assist in quantifying the effects of these kind of measures. It considers the effect of relevant factors like traffic composition, navigable width, quay-related activities etc. on the accident frequency. Use of the model, however, requires some nautical knowledge. The magnitude of the effect of measures on the accident frequency is limited to about 20% [WL95].

3.4.4 Modelling source term, dispersion, exposure and damage

After defining the loss of containment events and the resulting hazardous events, the source term and the dispersion in the environment will have to be calculated, and the exposure and damage determined. As the modelling in most cases does not differ from that described for stationary installations at establishments in chapters 4 and 5 of [RIVM99], only the specific aspects and differences are highlighted in this chapter.

Notes:

1. Two-phase outflow should be assumed. The release duration is to be determined using the transport unit inventory and the mass flow rate. In the QRA calculation, the release duration is limited to a maximum of 30 minutes.

2. The pool dimensions are determined by the equilibrium between the discharge rate, the evaporation rate, the solution rate and the rate of spreading under gravity. Models are described in [SAVE88].
   The presence of current elongates the pool. The maximum length is $u*t_{max}$, where u is velocity (m/s) and t_{max} is the time (s) when discharge rate and the loss terms reach equilibrium. In case of (immediate) ignition the equilibrium between burning rate and discharge rate determines the pool diameter as implemented in [IPORBM].

3. Other physical and chemical processes:
   - Sinking liquids are not considered in the QRA.
   - Evaporation models of liquefied gases [SAVE88], neutral or buoyant in water, are seldom used. Purely liquefied transport at atmospheric pressure does not actually take place.
   - Some substances react with water to produce flammable or toxic gases. Models to predict the release of flammable (mostly hydrogen) and or toxic gases (mostly hydrochloric acid) of substances that react with water have not been described. These substances (mostly substances of class 4.3 and 8 of the AD(N)R) are seldom transported in bulk.

4. Vapour cloud dispersion
   The direction of outflow is set as horizontal, parallel to the wind, because in an accident situation no specific information is available.
   In the case of direct ignition of a flammable gas, assume that the jet is unobstructed (free jet).
   In all other cases (delayed ignition flammable gas, continuous outflow of liquefied, compressed toxic gases) obstructed outflow should be assumed. The obstructed outflow is modelled as a jet with the impulse reduced by a factor 4 and with dimensions determined by the outflow conditions.

5. Chemical processes and the wet and dry deposition processes do not have to be considered in the modelling of the vapour cloud dispersion.

6. Exposure and damage should be modelled as described in chapter 5 of [RIVM99].

7. The meteorological data to be used in a QRA is described in section 4.10. Data from a representative meteorological station for the transport route under consideration should be used. If necessary, data from different stations should be used for different waterway sections.

8. A representative value for the aerodynamic roughness length Z_0 for the terrain surrounding the transport route as described in section 4.6.2 should be used. If necessary, different values should be used for different waterway sections.

9. Following the delayed ignition of a vapour cloud, depending on obstruction, either a flash fire or blast overpressures (explosion) result. Usually in waterway accidents the vapour cloud is unconfined. In the QRA only the occurrence of flash fires needs to be considered.

10. The population present in the surroundings of a transport route should be surveyed according to the rules outlined in section 5.3. Toxic substances dominate the societal risk. In cases where no toxic substances are being transported along a certain route, the population survey may be restricted to 200 metres from the waterway rim, but should be rather detailed e.g. a grid size of 25 metres should be used. When toxic gases are present, the survey should be extended to 2000 metres from the waterway rim. For distances over 200 metres a larger grid size e.g. 100 metres is sufficient. The same applies also beyond the beginning and the end of the calculation area.

3.4.5 Calculation and presentation of results

3.4.5.1 Individual Risk

The results of a QRA are the Individual Risk and the Societal Risk and have to be presented clearly as described in section 6. A widely used method for the calculation of risks is described in section 6.
The spacing of accident locations should be less than or equal to 25 metres because flammable liquids dominate the risk at short distances. The resulting risk contours should be smooth and should not reflect discontinuities due to a too wide spacing of accident locations.

The same applies to the edges of the calculation area. Contours for limited sections that intersect with the waterway should not be presented. The calculated area should therefore be larger than the area to be presented in the report. When toxic substances are present, usually about 1000 metres extra on both sides is needed. In cases where only flammables are present, usually about 200 metres extra on both sides is enough. The criterion is that the risk contour does not change substantially when the number of accident locations is increased.

Attention should be paid to the distribution of the traffic over the width of the waterway. A uniform distribution is applicable unless specific reasons for some other distribution are present, such as a limitation in passage by bridges, a prohibition in passing or landing etc.

3.4.5.2 Societal Risk

Calculation of societal risk should be performed as stated in chapter 6.2 of [RIVM99]. The remarks on the spacing of accident locations and the distribution of the traffic on the waterway apply here as well. Care should be taken to avoid overlap between populated grid cells and the waterway (most programs check on this).

The size of the area to be surveyed for numbers of inhabitants depends on the composition of traffic as given in Table 3.14, derived from [AEA95] and [IPORBM].

Table 3.14 Distances from waterway-edge to survey population for societal risk calculation

Substances present	Distance from edge (m)
Flammable liquids	50
Flammable gases	500
Toxic liquids	500
Toxic Gases	2000

Societal risk, when compared to the Dutch government standards, should be calculated and presented per kilometre route. Decisive for the comparison is the kilometre that produces the maximum societal risk.

3.4.6 Presentation of results

Results should be presented as stated in chapter 6.3 of [RIVM99]. As well as the presentation of the Individual Risk and the Societal Risk, other results can be presented which will give a picture of the risks. Useful presentations include graphs of the probability of death along the centre line as a function of distance for the dominant LOCs. Also those waterway sections with the highest risks or the waterway sections and locations which do not comply with the risk standards may be highlighted. The contribution of the different substances or substance categories, or the contribution of the transport during daytime or night-time to the overall risks may be specified.

3.5 Pipeline transport

3.5.1 Introduction

This chapter gives an outline of a QRA for the transport of dangerous substances by pipeline. The loss of containment events (LOCs) that need to be included in the QRA are identified. The corresponding failure frequencies and the various events following a release and their probabilities are given. The modelling of the source term, dispersion, exposure and damage, and the calculation and presentation of the results is not described in detail. Only the differences in modelling as compared with stationary installations are highlighted.

The data required for a QRA are:
- Description of the transport system (diameter, location emergency valves);
- Description of the transport stream (substance, flow rate);
- Description of the ignition sources;
- Properties of transported substances;
- Terrain classification of the surroundings of the transport route;
- Meteorological data;
- Population distribution in the surroundings of the transportation route.

Guidelines for obtaining these data, recommended values and references to information sources are given in paragraph 4.5.

Notes:

1. This chapter only applies to underground cross-country pipelines.

2. This chapter does not always apply to the pipeline transport of methane and flammable liquids (K1, K2 or K3). For these substances special tables apply that prescribe the distance between a pipeline and nearby housing, if defined safety measures are taken. These tables are implemented in [IPORBM].

3.5.2 Loss of Containment Events

For underground pipelines two LOCs are defined [SAVE95b]. The LOCs are:
- leakage from a 20 mm hole in the pipeline;
- rupture of the pipeline.

3.5.3 Accident and outflow frequency, events and event probabilities

The accident frequency equals the frequency of outflow and is given per km per year. Table 3.15 presents the accident frequency for the different types of underground pipelines [SAVE95b].

Table 3.15 LOC frequencies for various types of pipelines

Pipeline type	Accident Frequency (1/km.yr)
Line located in a “lane”	$7.0 * 10^{-5}$
NEN 3650 - line	$6.1 * 10^{-4}$
All other lines	$2.0 * 10^{-3}$

Notes:

1. Line located in a “lane” means a pipeline located in a group of pipelines, on a dedicated route. LOC frequencies for this situation are lower because of extra preventive measures.
2. For specific pipelines other frequencies may be used such as if additional preventive measures are proving to decrease the LOC probability. (This applies for instance to a chlorine line in the Rijnmond area.)

The probability of leakage or rupture, given an LOC, is given in table 3.16.

Table 3.16 Leakage and rupture probability, given an LOC

Pipeline type	Leakage probability	Rupture probability
Line located in a lane	0.9	0.1
All other pipelines	0.75	0.25

The hazardous events following an LOC are:
- toxic exposure
- jet fire
- fireball
- pool fire
- flash fire
- explosion.

The immediate ignition probabilities for LOC are given in table 3.17 [SAVE95b].

Table 3.17 Immediate ignition probability for a LOC

Type of substance	Probability of immediate ignition	
	Leakage	Rupture
Flammable gas	0.04	0.09
Liquefied flammable gas	0.14	0.30

The probability of a delayed ignition is, at the most, equal to: (1 - probability of immediate ignition), because there is a probability of no ignition at all.

Note:

1. A higher probability of direct ignition may be considered in the case of hydrogen, given its low minimal ignition energy.

3.5.4 Modelling source term, dispersion, exposure and damage

The next step, following completion of the LOCs, concerns the calculation of the source term. For this calculation a distinction has to be made between leakage and rupture.

3.5.4.1 Leakage

If there is no possibility that the LOC will be noticed, and actions to close (emergency) valves can not take place or might fail, the leakage is considered to be a continuous source lasting for 30 minutes.
If (emergency) valves are closed, then for
- gas: release will continue until the pressure in the pipeline equals the atmospheric pressure;
- liquid: release will take place due to liquid expansion until the vapour pressure in the pipeline equals atmospheric pressure. If the pipeline is not level, outflow due to gravity forces should be considered;
- liquefied gas: two phase outflow occurs.

Note:

1. A comparison between the outflow rate and the pump rate gives some information about whether the leakage might be noticed by the pipeline operator.

3.5.4.2 Rupture

In case of a rupture, the calculated outflow should be doubled because of two-side outflow. Furthermore, the outflow should be increased by the pump rate until the pump is stopped or valves are closed. Gravity forces (liquid lines) should also be taken into account.

Notes:

1. It should be checked whether the pump rate will increase because of the pressure drop due to the pipeline rupture.

2. Crater formation and location of the hole (direction of outflow) is not taken into account because of lack of reliable data.

3. The agreed maximum pool size is 3000 m^2 with a pool depth of 0.1 m.

4. Given the critical temperature of ethene, the outflow of ethene in the event of a pipeline rupture is sensitive to the assumed air and soil temperature [SAVE95b]. For leakage it is shown that there is hardly a difference in risk, whether the outflow is calculated as a gas flow or a two phase flow.

5. The evaporation factor for soil equals 1800 $W/K.s^{1/2}$.

6. The meteorological data to be used in a QRA is described in section 4.10. Data from a representative meteorological station for the transport route under consideration should be selected. If necessary, data from different stations should be used for different sections of the pipeline.

7. A representative value for the aerodynamic roughness length Z_0 for the terrain surrounding the transport route as described in section 4.6.2 should be selected. If necessary, different values should be used for different line sections. Default value Z_0=1.0 metre.

8. Chemical processes and the wet and dry deposition processes do not have to be considered in the modelling of the vapour cloud dispersion.

9. Exposure, and damage should be modelled as described in chapter 5.

10. The population present in the surroundings of a transport route should be surveyed according to the rules outlined in section 5.3.

After defining the source term, the modelling does not differ from the modelling described for stationary installations.

3.5.5 Calculation and presentation of results

The results of a QRA are the Individual Risk Contours and the Societal Risk Graphs. A widely used method for the calculation and presentation of risks is described in section 6. According to current regulations, the Societal Risk Graphs have to be calculated and presented per kilometre of transport route.

Notes:

1. The size of the calculation grid should be small enough not to influence the calculation results.

2. Accident locations have to be selected at regular distances and beyond the beginning and end of the section under consideration to produce smooth risk contours. There should be enough locations to ensure that the risk contour does not change substantially when the number of accident locations is increased.

3. In the calculation of the Societal Risk, the choice of the beginning and end of the sections for which the results are presented may be arbitrarily set beforehand. However, sections should be chosen in such a way that the Societal Risk is maximised.

4. BASIC DATA

4.1 Introduction

To perform a QRA of a technical system the first step is defining this system, its characteristics, and its boundaries. Transport systems present some special difficulties in this respect. There is a wide variety of possible accident-site characteristics and also a wide variety of transport units and substances may be involved.

The basic data needed in conducting a QRA for a specific transport route include the:
- Description of the transport route (location, type of route, obstacles present)
- Description of the transport streams (annual number of transport units per substance or category, during daytime and night-time)
- Description of the number of accidents and traffic intensities in order to determine accident frequencies
- Description of the transport units (type of unit, characteristic inventory)
- Description of the ignition sources
- Properties of transported (representative) substances
- Terrain classification of the surroundings of the transportation route
- Meteorological data
- Population present in the surroundings of the transportation route

In chapter 3 methods for obtaining these data, recommended values, and references to information sources for most of the data items mentioned above were given. The method for the categorisation of substances used in IPORBM and in a QRA in the Netherlands is described in paragraph 4.2. The application of this method to a QRA for road and inland waterway transport of hazardous materials will be outlined. Furthermore, the subsequent paragraphs will describe how data on the transport of hazardous substances in the Netherlands may be obtained, and how a location specific accident frequency may be deduced for a specific section of a transport route from the available databases in the Netherlands.

4.2 Categorising substances

4.2.1 Description of method and criteria

Due to the wide variety of substances that are transported, there is a need to define a limited number of substance categories, and to classify each transported substance within this scheme. Quantitative risk calculations may then be based on these categories and on a substance representative of a particular category. The method has been described in [AVIV95] and [AVIV99]. This classification is based on the state of aggregation, volatility, flammability and toxicity. For transport on waterways, some additional properties are used i.e. solubility, reactivity with water and relative density. The scheme is related to the classifications for the transport of hazardous materials as applied in the ADR, RID and ADNR. The four main categories are given in Table 4.1.

Table 4.1 Main substance categories for risk calculations

Category	**Description**
GF	Flammable gas
LF	Flammable liquid
GT	Toxic gas
LT	Toxic liquid

In each main category, one or more subcategories are defined and labelled numerically; a higher number indicates a higher risk potential. For example, an LT4 substance is ‘more dangerous’ than an LT1 substance. Substances that are both flammable and toxic are indicated by a combined category, for example Ethylene oxide (UN 1040) is categorised as GF1/GT3.

The divisions and subdivisions of the substance categories for a risk calculation are given below. The subcategories GFO and GTO include compressed gases or refrigerated liquids. These categories, in most cases of practical interest, can be omitted in a QRA.

Definitions

Definition state of substances	
Gas	T_{boil} < 293 K
Liquid	T_{boil} > 293 K and T_{melt} < 293 K
Solid	T_{melt} > 293 K

Definition of parameters	
LC_{50}	LC_{50} – ihl – rat – 1 hr [ppm]
T_{crit}	critical temperature [K]
T_{boil}	boiling temperature at 1 bar [K]
P_{20}	vapour pressure at 20°C [mbar]
T_{flash}	flash point [K]
T_{melt}	melting point [K]

Subdivisions

GF Flammable gas	IMDG “flammable”	
	ADR/RID class 2.2, 2.4 ; item number F, TF, FTC	
T_{crit} < 293 K	GF0	T_{boil} < 182 K
T_{crit} > 440 K	GF1	T_{boil} > 273 K
T_{crit} 400 – 440 K	GF2	T_{boil} 253 – 273 K
T_{crit} 293 – 400 K	GF3	T_{boil} 182 – 253 K

GT	Toxic gas	LC_{50} < 5.10^4				
	T_{crit}	< 10^2	10^2–10^3	10^3–10^4	10^4–5.10^4	T_{boil}
	T_{crit} < 293 K	GT0	GT0	GT0	GT0	T_{boil} < 182 K
	T_{crit} > 440 K	GT5	GT4	GT3	GT2	T_{boil} > 273 K
	T_{crit} 400 - 440 K	GT5	GT5	GT4	GT3	T_{boil} 253 – 273 K
	T_{crit} 293 - 400 K	GT5	GT5	GT5	GT4	T_{boil} 182 – 253 K

LF	Flammable liquid	T_{flash} < 334 K (<61 C)
	LF1	T_{flash} > 296 K (>23 C)
	LF2	T_{flash} < 296 K (>23 C)

LT	Toxic liquid	LC_{50} < 5.10^3				
	P_{20}	< 10^1	10^1-10^2	10^2-10^3	10^3-5.10^3	T_{boil}
	P_{20} < 10	LT2	LT1			T_{boil} > 373
	P_{20} 10 – 50	LT3	LT2	LT1		T_{boil} 353–373
	P_{20} 50 – 200	LT4	LT3	LT2	LT1	T_{boil} 323–353
	P_{20} 200 – 700	LT5	LT4	LT3	LT2	T_{boil} 303–323
	P_{20} > 700	LT6	LT5	LT4	LT3	T_{boil} < 303

Additional points for transport on water
For transport on waterways, the following specific additional points should be addressed:
- Sinking substances, that is substances with a relative density to water at 20°C > 1.03, are disregarded;
- Substances reacting with water to yield toxic or flammable gases do not have to be considered in the QRA. The amount of substances transported (in bulk) is small. Also specific source term models have not been developed or incorporated in commonly used integrated software packages.
- In case the relative density to water at 20°C is less than 1,03 and P_{20} is less than 700 mbar the solubility of the substance should be considered, for example in the source term and effect calculation of the QRA. Alternatively, as a good approximation, the substance category number may be lowered by 1. For example, a readily dissolving substance (i.e. solubility > 4000 mol/m^3) of LT2 can be considered as LT1.

4.2.2 Use of method in a QRA

The most precise result in a QRA is of course achieved by calculating for all substances. However, this requires a large amount of input data such as substance properties data. The method may be applied at two different levels of detail depending on the demands of the project involved [AVIV95, AVIV99].

If a quick indication of the risk levels is sufficient, one, representative substance for each substance category involved can be used to perform the calculation. The recommended representative substances are summarised in Table 4.2.

Often, a few specific substances account for the bulk of transport in a substance category. A more precise result may then be achieved by calculating these substances as such and approximating only the last 20% of the transported substances by using a representative substance (80/20-rule).

Table 4.2 Representative substances per substance category

Substance category	Representative substance
LF1	Nonane
LF2	n-Pentane
LT1	Acrylonitrile
LT2	Nitric acid (70%) *)
LT3	Acroleine
LT4	Methylisocyanate
LT5	(not transported in bulk)
LT6	(not transported in bulk)
GF0	Not considered in a QRA
GF1	Methylmercaptan **)
GF2	n-Butane
GF3	n-Propane
GT0	Not considered in a QRA
GT2	Ethylchloride ***)
GT3	Ammonia
GT4	Sulphur dioxide
GT5	Chlorine

*) When used for studies on waterway transport do not consider sinking and dissolving.
**) Just consider flammability.
***) Take substance properties at 293 K.

4.3 Road transport

4.3.1 Transported substances

In order to specify the LOCs for accidents in the transport of hazardous materials, information on the substances transported and the packaging of substances are essential. For the transport by road in the Netherlands this information is unfortunately not automatically collected and stored, in contrast to the transport by rail or on inland waterways. However, in recent years information has become available by means of visual registrations made at a significant number of locations. For most of the main roads in the Netherlands, information on the annual transport and composition of transport (number of transport movements per substance category) is given in [AVIV97]. As the typical observation period lasted only 8 hours, the estimated transport streams are to a certain degree uncertain and give merely an indication of the magnitude of the transport. Essentials of the adopted working procedures are given in [AVIV97].

4.3.2 Determination of location specific outflow frequencies

In a QRA for road transportation the outflow frequency has to be specified. The outflow frequency is defined as the frequency of an accident with a hazardous substance transport unit where at least 100 kg of the transported substance is released. Generic values (per transport unit km) for different road types are given in chapter 3.2.

In a detailed QRA the use of location specific outflow frequencies for main roads is recommended. As the number of hazardous material accidents is too small for deriving a location specific outflow frequency, it is current practice in the Netherlands to assume that the outflow frequency is a linear function of the injury accident frequency. The outflow frequency for a particular road section may then be determined by multiplying with the ratio of the (location specific) injury accident frequency to the average injury accident frequency for that road type in the Netherlands.

The procedure for the derivation of a location specific outflow frequency involves the determination of:
- The number of accidents.
- The amount of traffic.
- The location specific injury accident frequency.
- The ratio of the location specific injury accident frequency to the average injury accident frequency.

The location specific injury accident frequency should be derived as the quotient of the number of injury accidents and the amount of traffic (number of motor vehicle kilometres) in a corresponding period using similar selections. Road data, number of motor vehicles, and motor vehicle accidents are registered in databases maintained by the Traffic Research Centre AVV of the Ministry of transport, Public works and Water Management:
Characteristics of main roads can be retrieved from the database WEGGEG.
The number of accidents may be retrieved from the database VOR. A subset of this database, IMPULS, contains all accidents on the main roads on a hectometre basis.
Amounts of traffic for approximately 1000 sections of the main roads can be obtained from the database INWEVA.
Local authorities (Regional Directorates of Rijkswaterstaat (the Department of Public Works) and Provincial and Community Road management) should be consulted to obtain relevant data for other road types.

Average injury accident frequencies (number of injury accidents for every million kilometres travelled by motorised road vehicles per year) for the Netherlands are derived for several road types: motorways, secondary and tertiary roads outside built-up areas and major arteries inside built-up areas [SWOV97].

Notes:
1. Review of the distribution of the location of accidents along a certain road section may indicate possible concentration points. Whether this is significant can be statistically checked. A method, which assumes that the accidents are binomially distributed, is outlined in [AVIV94].

2. In the derivation of a specific outflow frequency a comparison has to be made between the location specific accident frequencies and an average injury accident frequency. lt should be ascertained as to whether the accidents and amount of traffic used in deriving the location specific accident frequencies refer to the same selection as used in deriving the average accident frequency.

4.4 Railway transport

4.4.1 Transported substances

In order to specify the LOCs for accidents on private sidings, shunting yards and railways, information on the transport stream is required. This concerns specifically the number of atmospheric and pressurised tank cars per period (usually one year) and the identification of the substances involved. The information source differs by activity:

- For a private siding, transported goods are usually only used by this establishment. Therefore the substances involved are roughly known. Furthermore, as the private siding is a part of the establishment, the permit of the establishment contains information on the number of cars and the substances;
- A shunting yard is an establishment with its own permit. This permit should contain all the required information on the number of tank cars and substances;
- The main railway operator in the Netherlands, NS Cargo, keeps records of the transport (number of cars combined with substances) of railway tank cars on the Dutch railway network. This information is not publicly available, but has to be ordered from NS Cargo.

4.4.2 Determination of location specific outflow frequencies

In section 3.3 generic values for outflow frequencies are given for private sidings, shunting yards and the railway network. It is strongly recommended to apply these generic values as there are no publicly accessible databases or reports available on the numbers and types of accidents for a specific private siding, shunting yard or part of the railway network.

However, all accidents on the railways are reported to the Dutch Railways (also from shunting yards). If the accident is severe enough, a detailed investigation takes place. The Dutch railways keep record of all reported accidents. lt is not easy, however, to retrieve sufficient information, that will justify the use of specific outflow frequencies for the location under consideration.

4.5 Inland waterway transport

4.5.1 Transported substances

4.5.1.1 Introduction

In order to specify the LOCs for accidents in the transport of hazardous materials, information on the substances transported and the packaging of substances are essential. For the inland waterways in the Netherlands this information is stored in the IVS90 system. In IVS90 a particular transport movement is tracked from sender to destination. At a number of locks, data on the passages of ships and their contents are registered in a standard format.

The annual transport and composition of transport on a specific section of a waterway may therefore be retrieved from IVS90. In the next paragraphs the essentials of the working procedures are given.

4.5.1.2 Transported quantities

To find the annual quantity transported per substance along a specific section of a waterway the local manager of the waterway should be contacted. IVS90 is partitioned into 5 regions: Grote rivieren, Zuid West, Midden Nederland, Noord en Zuid Oost. Every region is divided into a number of blocks. For a specific year the IVS90 standard records of the nearest IVS-block should be requested. Normally the most recent three-year period is sufficiently accurate. On querying these records the following conditions should be applied:

Table 4.3 Conditions for retrieving shipped quantities from IVS90-records

Item	Condition	Remark
Mass	> 30 tonnes	Standard LOCs for tank ships must apply
Cargo type	2	Code for AD(N)R substances
Vessel type	2, 4, 6, 8, 10, 12, 14, 16, 18, 30-39, 49, 52-54	IVS90 ship-type codes for transport in bulk (tanks); containers and solids in bulk are not usually considered in a QRA

In IVS90 the substances are registered by their UN-number. A vessel may, however, contain more than one tank and several different substances. The standard LOCs assume leakage of one tank. The frequency of impact per tank is, as a first and rough approximation, given as the inverse of the total number of tanks in the vessel. The analysis should result in a list of UN-numbers (substances) and the number of vessel and tank passages. As such this may not be an adequate input for a QRA. The number of substances may be reduced to a practical number by categorising, as described in paragraph 4.2 above. Also the relation between substance (category) and vessel type should be specified. This is outlined in chapter 3.4.

It is possible to select from IVS90 specific sender-destination combinations in order to analyse their contribution to the total risk. Destinations are represented in the IVS90 by a numerical code. It is also possible to select a specific type of vessel for analysis or focus on some other aspect depending on the character of the QRA.

When future developments are important some use can be made of forecasting studies like [NEA97] and [NEA98]. However, forecasts on the level of specific hazardous substances are rarely available. Extrapolating from the forecast for all commodities or for vessel passages is not the proper way but often the best attainable.

4.5.2 Determination of location specific accident frequencies

4.5.2.1 Introduction

The location specific accident frequency as an adequate input for a detailed QRA should be derived as the quotient of the number of vessel accidents with serious damage and the amount of traffic (number of vessel kilometres) in a corresponding period. Accidents on waterways are registered in the ONOVIS database maintained by the Traffic Research Centre AVV of the Ministry of Transport, Public works and Water Management. The amount of traffic (passages/year) may be retrieved from IVS90. The accident frequency may therefore be deduced from ONOVIS and IVS90 together. In the next paragraphs the essentials of the working procedures are given.

4.5.2.2 Accidents

Accidents on inland waterways in the Netherlands are reported by a number of parties (river police, regional authorities) and are nationally registered in the ONOVIS database. For a specific section of a waterway, data on the number of vessels involved in accidents and the damage may be retrieved from ONOVIS of the Traffic Research Centre AVV. For a QRA the most recent 5 years should be considered. A check should be performed as to whether major modifications of the waterway were undertaken or other circumstances changed in that period. On querying the records of ONOVIS the following conditions should be applied:

Table 4.4 Conditions used for retrieving accident data on the main waterway from ONOVIS records

Item	**Condition**	**Remark**
“Zijvaartaanduiding” (branch indication)	“geen” (none)	Selects accidents on main waterways and not the accidents in harbours or branches
“Shiptype” (type of vessel)	<=69	Selects accidents with working barges
“scheepsschade omschrijving” (description of ship damage)	“zwaar” (serious)	Selects accidents with serious damage. Serious damage is considered as an event where release is a possible consequence
“scheepsschade omschrijving” (description of ship damage)	<>“geen” (none)	Selects all damages. When no serious damages are encountered, the frequency of a serious damage may be estimated as a fraction of all damages (Table 4.6)

The items “vaarwegnummer” (waterway number) and “kilometre” indicate the location of the accident. A description of these locations may be found in [AVV97a]. A crosscheck on the location with the field “accident_description” should always be performed.
For gas tankers a more severe damage class (formerly called “class 4”) is needed to produce a release of product. Only when independent data on this damage class are lacking may default values for the damage class fraction be taken from Table 4.5 [AVIV93].

Table 4.5 Damage class relevant to gas tankers as a fraction of total serious damages (only to be used when lack of other data)

Navigability class (CEMT)	**Gas tanker damage class as a fraction of total serious damages**
4	0.14
5	0.19
6	0.32

When no accidents with serious damages are encountered (and *only* then, as this is a rough approximation!), the number of accidents with serious damage may be estimated as a fraction of the total number of accidents with damage (all-damage classes). This fraction is derived from [AVIV93] and is given in Table 4.6.

Table 4.6 Serious damage as a fraction of all damages (rough approximation in lack of other data)

Navigability class (CEMT)	**Serious damages as a fraction of all damages**
4	0.16
5	0.27
6	0.34

Summarising:
1. Find the number of serious damages in the period considered from the ONOVIS database.
2. When no serious damages occurred in the period considered, find the number of all-damage classes from the ONOVIS database and multiply this by the fraction from Table 4.6.
3. Find the number of the more severe damages (relevant to gas tankers) either from the database or apply the fraction from Table 4.5 to the number resulting from step 1 or step 2.

When the result of Step 1 or 2 is divided by the number of years and by the number of kilometres considered this gives the damage *density* (per km.yr) for single hull and double hull vessels. When the result of Step 3 is divided by the number of years and by the number of kilometres considered this gives the damage *density* (per km.yr) for gas tankers. To calculate the damage *frequency* (per vessel km.) the amount of traffic needs to be taken into account.

4.5.2.3 Amount of Traffic

The amount of traffic (passages/year) may be retrieved from IVS90 or from the annual publications of the Traffic Research Centre AVV [AVV97b]. Recreational traffic is not considered.

4.5.2.4 Determination of accident frequency

The location specific accident frequency, as an adequate input for a detailed QRA, is derived as the quotient of the number of accidents with serious damages and the amount of traffic (number of vessel kilometres) in the corresponding period. A frequently encountered problem is whether a specific section of the waterway can be regarded as nautically homogeneous, that is whether it may be assumed that the accidents that occurred at specific locations on the waterway section might just as well have happened anywhere else along that section. A review of the distribution of locations of accidents along the waterway may indicate possible concentration points. Also, a nautical expert may judge whether (and which) specific local factors are present that may explain an increased accident rate. If so, the accidents (or some of them) have to be considered specific for that location. If not ("the accidents might as well have happened anywhere else along the section") the accidents should be considered representative for the total length of the nautically homogeneous section. From studies, it appears that passages involving bridges or locks bring about very specific accidents that are not representative for adjacent sections of the waterway, and these accidents are therefore assigned to a specific location.

When risk-reducing measures are considered and evaluated in a detailed QRA, a model is needed which links the characteristics of the waterway and the amount of traffic to the accident frequency. The Traffic and Accident model (V&O model [MSCN95], [AEA95]) of the Traffic Research Centre AVV performs that task. Based on traffic simulations and observed correlations in waterway- and accident-characteristics, this model calculates the effect on the accident frequency of variations in, for example, navigable width or amount of traffic and composition. For the purpose of calculating the risks of future developments, the V&O-model may also be applied in studying the effect of forecasted changes in amount of traffic and traffic composition. The application of the V&O model, however, requires some nautical expertise.

4.6 Pipeline transport

4.6.1 Transported substances

The substance transported through a selected pipeline is usually well known. Nearly all pipelines are designed and built for the transport of one substance only. For the transport of this product only a permit is usually given. There are, however, a few pipelines through which more substances than one are transported (not at the same time). This permit of this pipeline should provide the required information.

4.6.2 Determination of location specific outflow frequencies

Paragraph 3.4.3 presents the generic values for the outflow frequencies of pipelines. The use of these values is strongly recommended. This is because the number of accidents for a specific location is usually very low and it takes quite a number of years to come up with a reliable frequency.

5. REFERENCES

[ADNR] Reglement voor the vervoer van gevaarlijke stoffen over de Rijn (Regulations for the carriage of dangerous substances over the Rhine), SDU, The Hague, 1998

[AEA95] Handleiding risicobepalingsmethodiek en doorrekenen maatregelen (Manual for risk determination method and the consequences of measures), AEA Technology Netherlands B.V., The Hague, 1995

[AVIV93] Aandachtspunten Hoofdvaarwegen (Points of interest for Major waterways). AVIV, Enschede,1993.

[AVIV94] Fundamenteel onderzoek naar kanscijfers voor risicoberekeningen bij wegtransport gevaarlijke stoffen. (Fundamental research on probability numbers for risk assessment of road transport) Enschede: AVIV, 1994.

[AVIV94] Handleiding risicoberekening wegtransport gevaarlijke stoffen. Bepaling faalkansen. (Manual for risk assessment of road transportation of dangerous substances. Specification of chances of failure) AVIV, Enschede, 1994.

[AVIV95] Methodology for categorising substances in risk calculations of the transport of hazardous materials. Safety on waterway transport project S3b. AVIV, Enschede, 1995.

[AVIV99] Methodology for categorising substances in risk calculations of the transport of hazardous materials. AVIV, Enschede 1999 (to be published).

[AVIV97] Risico's wegtransport gevaarlijke stoffen (Risks of road transport of dangerous substances) AVIV, Enschede, 1997.

[AVV] Wegwijzer voor de binnenscheepvaart (Handbook for inland navigation). AVV, Rotterdam

[AVV97a] Vaarwegen in Nederland (Waterways in the Netherlands). Ministry of Transport, Public Works and Water Management, Advisory service Traffic and Transport, Rotterdam, 1997.

[AVV97b] Kerncijfers hoofdvaarwegen. (Key data main waterways) Ministry of Transport, Public Works and Water Management, Advisory service Traffic and Transport, Rotterdam 1997.

[Buis] Structuurschema Buisleidingen (Structure Scheme for Pipelines) Kamerstuk 11; 173 53, nrs. 1-2

[CPR14E] Committee for th eprevention of disasters,Methods for the calculation of physical effects (the "Yellow Book"), The Hague SDU 1997, PGS 2.

[IPORBM] IPO RisicoBerekeningsMethodiek IPO (IPO Risk Calculation Methodology). AVIV, Enschede, 1997.

[MSCN95] Kok M., Tak C. van der, Gebruikershandleiding van het verkeers- en ongevalsmodel versie 1.2, (Users Guide to Traffic and Accident Model Version 1.2), MSCN Wageningen, 1995

[NEA97] Beneden rivieren also hoofdtransportas, Scheepvaartprognoses 2015. (Tidal rivers as main transporters, Shipping forecasts 2015) NEA, Rijswijk 1997.

[NEA98] Scheepvaartprognoses Zeeburg en Lekkanaal (Shipping forecasts Zeeberg and Lekkanaal). NEA, Rijswijk, 1998.

[NEN92] Eisen voor stalen transportleidingen (Requirements for steel transport lines). NEN 3650,1998.

[PROT98] Protocol QRA seagoing vessels: a project proposal, Ministry of Transport, Public Works and Water Management, 1998.

[RIVM99] Guideline for Quantative Risk Assessment.

[SAVE88] Risico's van het bulkvervoer van brandbare en giftige stoffen over het water (Risks of bulk transport of flammable and toxic substances by water), SAVE, Apeldoorn, 1988.

[SAVE95] Basisfaalfrequenties voor het transport van gevaarlijke stof over de vrije baan (Basic failure frequencies for transport of dangerous substances on open rail track). Report 951675-556, produced for N.V. Nederlandse Spoorwegen. SAVE, Apeldoorn, 1995.

[SAVE95a] Basisfaalfrequenties voor het transport van gevaarlijke stoffen per spoor (emplacementen). (Basic failure frequencies for transport of dangerous substances in rail yards). Report 951599, SAVE, Apeldoorn, 1995.

[SAVE95b] Risico's vervoer gevaarlijke stoffen, deelproject A74: buisleidingen; deel 1 (Risks of the transport of dangerous substances, project A74: pipelines; part l). Report 951250- 586, produced for workgroup IPO-A74, SAVE, Apeldoorn, 1995.

[SAVE97] Handleiding/protocol voor het uitvoeren van een QRA voor goederenemplacementen. (Handbook/protocol for the carrying out of a QRA for goods yards). Report 971071 - A27, produced for the Ministry of Transport, Public Works and Water Management. SAVE, Apeldoorn, 1997.

[SWOV97] Risico's onderscheiden naar wegtype (Risk differences between road types). R-96-62. SWOV, Leidschendam, 1997.

[V&W89] Nota risico's van het bulkvervoer van brandbare en giftige stoffen langs de vaarweg Rotterdam-Duitsland, Bijlage 1 (Note on the risks of bulk transport of flammable and toxic substances along the waterway Rotterdam-Germany, Annex 1) The Hague, Ministry of Transport, Public Works and Water Management, 1989

[VeVoWeg96] Eindrapport deelnota 3; handreiking risicobepalingsmethodiek externe veiligheid vervoer gevaarlijke stoffen over de weg & voorbeeldstudie. Project Veiligheid Vervoer over de Weg. (End report part 3: Handbook for risk determination method for external safety of transport of dangerous substances by road and example study. Project Safety of Transport by Road) The Hague: Ministry of Transport. Public Works and Water Management, 1996.

[VNG98] Handreiking externe veiligheid vervoer gevaarlijke stoffen, (Handbook on external safety in the transport of dangerous substances) Association of Dutch Communities; Ministry of Transport, Public Works and Water Management; Ministry of Housing, Spatial Planning and Environment; Ministry of Internal Affairs, The Hague 1998

[VROM84] Zonering langs hoge druk aardgastransportleidingen (Zoning along high pressure natural gas transport lines) Circulaire van de minister van VROM (Circular of the minister of Housing, Spatial Planning and Environment), 26 November 1984 Reference DGMH/B no. 0104004.

[VROM91] Circulaire voor de zonering langs K1-, K2-, en K3-vloeistofleidingen. Bijlage bij brief van minister van VROM van 24 april 199l. (Circular for the zoning along K-1, K-2, and K-3 liquid lines. Annex to the letter of the minister of Housing, Spatial Planning and Environment of 24 April 1991) reference DGM/SR/1221254.

[VROM95] Risicobenadering voor NS-goederenemplacementen. (Risk approach for NS freight yards). VROM-circulaire (Circular of the Ministry of Housing, Spatial Planning and Environment), 1995.

[VVoW95] Systematiek voor indeling van stoffen ten behoeve van risico-berekeningen bij het vervoer van gevaarlijke stoffen. Project Veilig Vervoer over Water; Deelproject S3b. (System for the categorisation of substances with respect to risk calculations for the transport of dangerous substances). The Hague: Ministry of Transport. Public Works and Water Management, 1995.

[VW98] Quantitative risk assessment for transportation of hazardous materials. IPO Risk Calculation Methodology. Road-Rail-Water-Pipeline. The Hague, Ministry of Transport. Public Works and Water Management, 1998.

[WL95] Kok M., Klopstra D., Jong J.H. de, Veiligheid Vervoer over Water: Modellering van maatregelen (Safe Transport by Water: Modelling of measures), Waterloopkundig Laboratorium (The Hydrodynamic Laboratory), Delft 1995.