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

An international comparison of four quantitative

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Benchmark study based on a fictitious LPG plant

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This investigation has been performed by order and for the account of the Ministry of Infrastructure and the Environment, within the framework of international benchmark.

Abstract

An international comparison of four quantitative risk assessment approaches
Benchmark study based on a fictitious LPG plant

The methods to determine external safety risks used in the United Kingdom, France, the Walloon Region of Belgium and the Netherlands are very different. The differences concern both the way the calculations are performed and the consequences calculated (such as deaths or health damage to persons). Despite the differences, the methods yield similar results in terms of the safety distances.

This conclusion can be drawn from a benchmark study of a fictitious LPG storage plant performed by experts of these countries. However, similar results can lead to different policy implications. For instance, the safety distances in the Netherlands and France are used as limit values, whereas in Belgium and the United Kingdom they are used as guide values.

Keywords: quantitative risk assessment, QRA, benchmark study, LPG, external safety

Rapport in het kort

Een internationale vergelijking van vier kwantitatieve risicoanalyse methoden
Benchmark studie op basis van een fictief lpg-bedrijf

De methoden die in het Verenigd Koninkrijk, Frankrijk, Wallonië (België) en Nederland worden gebruikt om externe veiligheidsrisico's te bepalen verschillen sterk van elkaar. Dat betreft zowel de manier waarop de berekeningen worden uitgevoerd als de aard van de effecten die worden berekend (zoals dodelijke slachtoffers of gezondheidsschade aan personen). Desondanks liggen de veiligheidsafstanden die met deze methoden zijn berekend dicht bij elkaar.

Dit blijkt uit een risicoanalyse die door experts uit deze landen is uitgevoerd van een fictief opslagbedrijf met lpg. Gelijksoortige uitkomsten kunnen overigens per land tot uiteenlopend beleid leiden. Zo gelden de veiligheidsafstanden in Nederland en Frankrijk als limietwaarden, maar in België en het Verenigd Koninkrijk als advieswaarden.

Trefwoorden: kwantitatieve risicoanalyse, QRA, lpg, externe veiligheid, benchmark studie

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Summary

Within the European Union the different countries use different risk assessment methods for the land use planning and the licensing of SEVESO II companies with dangerous materials. The question is if the different approaches also lead to different safety distances and different policy implications. In order to compare the Quantitative Risk Assessment (QRA) methods used in the United Kingdom, France, the Netherlands and the Walloon Region of Belgium, a benchmark exercise was performed for a fictitious LPG plant. This report contains the summary of the four approaches and the different results of the calculations and the policy implications of the results. The calculations were performed in the period of 2007-2009.

QRA approaches
INERIS (France) uses a semi quantitative risk based approach based on bow tie analyses. This results in the 'Natrice de Mesure de Maîtrise des Risques' (MMR matrix) and the 'Plan de Prévention des Risques Technologiques' (PPRT, comparable to individual risk). The MMR matrix shows the risk level (a combination of the severity and the probability) of each accidental scenario. Some cells (risk levels) of this matrix are 'unacceptable' and operators are required to implement new safety measures in order to reduce the probability or the severity of the scenarios involved. The PPRT shows different zones with different implications for land use. For existing constructions, possible measures proposed by the PPRT for high risk zones may be expropriation, relinquishment or reinforcement of buildings. For future constructions, possible measures proposed in the framework of a PPRT for high risk zones may be to forbid building developments or to apply specific conditions to the build of a new construction (related to the building resistance toward accidents).

In the United Kingdom the 'protection based concept' is used by the Health and Safety Executive (HSE) to determine three safety zones based on the hazard of the flammable substance. For LPG only a Boiling Liquid Expanding Vapour Explosion (BLEVE) is considered. These three zones are used by HSE to give an advice (against or not against) in case of a new development in those zones. Hereby, the developments are categorized into different categories related to vulnerability (e.g. the highest category concerns large hospitals, large schools and sports stadiums). The societal risk and the criteria to be used are under discussion in the United Kingdom, but for this benchmark study HSE calculated an FN-curve, with an upper and lower guide value.

The QRA in the Netherlands results in individual risk contours and an FN-curve (societal risk). The individual risk contour of 10^{-6} per year is the limit value: within this contour no vulnerable objects (e.g. houses, schools, hospitals) are allowed. For the societal risk a guide value is used. The competent authority must account for the height of the societal risk in relation to socio-economic benefits. The way to perform a QRA (scenarios and failure frequencies, the software program and guidelines) has been prescribed in the legislation. RIVM is responsible for the management and development of the guideline and the software program SAFETI-NL.

In the Walloon Region (Belgium) a probabilistic approach is used as well. The Major Risk Research Centre of the Faculté Polytechnique de Mons (FPMs) calculates risk curves around the SEVESO II companies. The risk contours calculated are based on an individual suffering irreversible injury. The area

delimited by the 10^{-6} per year iso-risk curve is called the 'consultation zone'. The competent authority gives an advice for every land use project inside this zone. For the decision-making, a matrix crossing the level of risk and the type of buildings is used to grant or deny the permit for a project (e.g. houses are not allowed inside the 10^{-5} per year iso-risk curve, and hospitals are not allowed inside the 10^{-6} per year iso-risk curve). The societal risk is not taken into account.

The four approaches show a difference between robust, generic (standardized) methods on one side and specific methods based on expert judgment on the other side. The choice of a 'generic' method (in the Netherlands, the Walloon Region and the United Kingdom) means that the QRA is not very well suited for analyzing risk reducing measures in detail; a specific approach (like the French approach) is more suitable for this objective. But a generic QRA method makes the QRA more transparent and robust. Further, the use of a generic QRA method doesn't mean a subsequent analysis is not possible at all. It is possible to see if the risks can be mitigated for example by reducing the risks of the most contributing scenarios (e.g. reducing the amount, relocation an activity).

Results of the benchmark study

To compare the different approaches, the four institutes used their own approach to calculate the risk of a fictitious LPG plant. At this fictitious LPG plant propane and butane is unloaded from rail tank cars and road tankers and is stored in vessels.

Scenarios and effect calculation

The results of the four risk assessments show differences in the scenarios (accidents), frequencies and effect calculations. In France the storage vessels of propane and butane are not considered when mounded or when some specific conditions related to safety are fulfilled. The (un)loading activities are, in this case, predominant. But in the United Kingdom and the Netherlands the vessels dominate the risk results.

Further, the selection of phenomena shows differences. For example, in the Netherlands and the Walloon Region a BLEVE of the vessels propane is not considered, because the vessels are mounded. However, HSE takes the BLEVE of the mounded vessels into account.

To get more insight in the differences, the effect calculations of the BLEVE of the butane sphere (700 m^3) and the flash fire of the mounded propane vessel (2500 m^3) were analysed. The largest distances of the BLEVE are between 380 and 920 meters. The distances of the flash fire are between 500 and 655 meters. The differences in effect distances can be explained by modelling differences (% of volume, process conditions, burst pressure of the BLEVE, parameters and software) and retained thresholds.

The thresholds (end of calculation) differ from the dose for irreversible damage (FPMs), the probit relation of heat radiation (RIVM) to the level of heat radiation used (different levels used by HSE and INERIS). The differences are also related to the different scope of the calculations. HSE and RIVM calculate the risk of people dying as a result of loss of dangerous materials. INERIS calculates the risk of people exposed to several predefined levels of intensity. In the Walloon Region, the risk is linked with the possibility of irreversible injury.

Safety distances
The relevant safety distances (guide value, limit value) calculated by the INERIS, HSE, RIVM and FPMs are between 200 and 280 meters for houses. That means that the safety distances are of equal dimension. Given the different approaches (semi quantitative, consequence based and probabilistic) and methodologies (different effect distances and thresholds), the similarity of the safety distances is surprising.

Policy implications
As mentioned, the resulting safety distances are of equal dimension. However, this doesn't mean the policy implications of the fictitious LPG site are the same. The decision depends on whether the development of buildings takes place within the safety distances. In France and the Netherlands a limit value is used; in the United Kingdom and the Walloon Region the safety distances are used to give an advice.

The implications of the societal risk vary. The MMR matrix in France shows the risk level of each scenario. In this benchmark four scenarios were considered as ´unacceptable´. That means that this case should not be authorized in France. Additional risk reduction measures will have to be implemented.
In the Netherlands a societal risk (FN-curve) is calculated and in the benchmark the guide value is exceeded. In the Netherlands the authority should account for the height of the societal risk.
The societal risk doesn't have an official status in the United Kingdom. Only for this benchmark HSE calculated an FN-curve. This curve is higher than the RIVM curve, but the guide value of HSE is less strict than the Dutch guide value and the FN-curve of the HSE is considered acceptable.
In the Walloon Region the societal risk is not taken into account.

Main conclusion
This benchmark study shows that the risk assessment methods used in France, the United Kingdom, the Netherlands and the Walloon Region are very different. Not only the methods and the guide values differ, but also the effect calculations with their end values (thresholds) vary. It is surprising that the resulting safety distances are of equal dimension. In order to understand the differences in detail and to improve the foundations and the value of the risk assessment methodologies, further international sharing of insights and methods is desirable.

1 Introduction

Within the European Union the different countries use different risk assessment methods for the land use planning and the licensing of SEVESO II companies with hazardous materials. The question is if the different approaches also lead to different safety distances and different policy implications. In order to compare the Quantitative Risk Assessment (QRA) methods used in France, the United Kingdom, the Netherlands and the Walloon Region of Belgium, a benchmark exercise was performed for a fictitious LPG plant.

The Institut National de l'Environnement Industriel et des Risques (INERIS) from France, the Health and Safety Executive (HSE) from the United Kingdom, the National Institute for Public Health and the Environment (RIVM) from the Netherlands and the Faculté Polytechnique de Mons (FPMs) from Belgium used their own QRA approach to describe the different scenarios and dangerous phenomena and to calculate the risks. Each organization wrote a report about the LPG case. The descriptions of the background information, the site description of the case, the scenario lists and the risk outcomes are attached in the appendices.

The calculations for this benchmark study were performed in the period of 2007-2009. In February 2008, three organizations (HSE, INERIS and RIVM) discussed the different approaches and the results of the case study during a meeting in Paris. The differences and the similarities of the risk results and the policy implications were listed. The fourth organization (FPMs) joined the group in October 2008. During this project the HSE contact person left the organization. That is the reason why there is no co-author from the HSE on this report.

This report contains the summary of the four approaches, their results and the corresponding policy implications. A summary of the four QRA approaches is given in chapter 2. Chapter 3 contains the description of the case. The main results are described in chapter 4: the critical dangerous phenomena and scenarios are listed, the Societal risk (SR) and the Individual Risk results are presented and the policy implications are discussed. Subsequently we pay attention to the similarities and differences based on the results in chapter 5. In the final chapter (chapter 6) the conclusions are presented.

A similar benchmark study for a flammable liquid depot was recently carried out by INERIS and RIVM [1]. In this study similar observations were made.

2 Brief overview of the four QRA approaches

Since the 1980s the United Kingdom and the Netherlands have based their external safety policy on the quantification of risks (probabilistic approach). In France before the Toulouse accident (2001), a deterministic approach was used. During the past few years, France has developed a (semi-quantitative) risk based approach. In the Walloon Region (Belgium), a probabilistic approach is used since 2003.

2.1 France

Risk Criteria

In France two different public decision tools use the output of the safety report and the risk assessment, namely the 'Matrice de Mesure de Maîtrise des Risques' (MMR) (Risk control measure matrix, related to the permit to operate process – based on a risk level comparable to societal risk) and the 'Plan de Prévention des Risques Technologiques' (PPRT) (Technological Risk Prevention Plan, related to land use planning – based on risk zones (called aléa levels) and comparable to individual risk).

In these public decision tools, the probability, intensity and the severity of potential major accidents are combined. The effect distances are expressed for three (for thermal and toxic effects) or four (for overpressure effects) pre-defined levels of intensity (see Annex 2 for more detailed information).

MMR matrix

The MMR matrix shows the risk level of an accident based on the combination of its severity and its probability of occurrence. The severity of major accidents is based on the evaluation of the number of persons exposed to different levels of intensity of dangerous phenomena. It is noted that the severity is based on the persons *exposed* and does not depend on the number of fatalities. The probability of occurrence ranges from A ($0\text{-}10^{-5}$ per year) to E (10^{-2}–1 per year).

Table 1 MMR Matrix

Probability **Severity**	**E** ($0\text{-}10^{-5}$ $^{-}$y)	**D** ($10^{-5}\text{-}10^{-4}$ $^{-}$y)	**C** ($10^{-4}\text{-}10^{-4}$ $^{-}$y)	**B** ($10^{-3}\text{-}10^{-2}$ $^{-}$y)	**A** ($10^{-2}\text{-}1$ $^{-}$y)
Disastrous	ALARP/ Unacceptable	Unacceptable	Unacceptable	Unacceptable	Unacceptable
Catastrophic	ALARP 2	ALARP 2	Unacceptable	Unacceptable	Unacceptable
Significant	ALARP	ALARP	ALARP 2	Unacceptable	Unacceptable
Serious	Acceptable	Acceptable	ALARP	ALARP 2	Unacceptable
Moderate	Acceptable	Acceptable	Acceptable	Acceptable	ALARP

This matrix consists of three different areas:

- The unacceptable areas where the risk of an accident is considered as unacceptable and where operators are required to implement new safety measures in order to reduce the probability or the severity of a major accident.
- The 'As Low as Reasonably Practicable' (ALARP) areas where operators are required to continuously improve the safety in their facility. The total number of accident scenarios in each ALARP 2 box must be 5 or lower.
- The acceptable areas where the risk of an accident is considered acceptable.

This risk matrix is applied for upper-tier SEVESO II establishments.

PPRT – Aléa maps (risk zones)
The land use planning and the land use measures are defined using aléa maps together with a specific governance process (involving local stakeholders) through the PPRT. It has been chosen here not to conduct the whole process of the PPRT. More information can be found in [1] and Annex 2. However, we will present the main recommendations for the actual land use and the land use planning that could be given on the basis of aléa maps. Aléa levels are visualized as contours on a map.

Table 2 Aléa levels

Maximum intensity	**Significant lethal**			**Lethal**			**Irreversible**			**In-direct**
Cumulative probability	D	5E to D	<5E	>D	5E to D	<5E	>D	5E to D	<5E	All
‘aléa levels’	VH+	VH	H+		H	M+		M	Low	

The combination of the Intensity of the effect (first line) and the probability (second line) gives the Aléa class (third line). For example, concerning land use measures and land use planning for housing, the following recommendation can be made for the highest aléas:
- red zones (VH+/VH): the risk is not acceptable and expropriation is possible;
- yellow/orange zones (H+/H): the risk will be not acceptable in the longer term and relinquishment is possible;
- red zone and yellow zone (VH+/VH/H+/H): no new construction allowed or specific conditions to the new construction are required (related to the building resistance toward accidents).

Regulation
The regulation related to SEVESO II facilities is gathered in the ‘Livre V du code de l’environnement’. The PPRT has been defined by the ‘Loi du 30 Juillet 2003 relative à la prévention des risques technologiques et naturels et à la réparation des dommages’ [2]. The risk matrix has been defined in the ‘Arrêté du 29 Septembre 2005’ [3]. A number of regulatory texts exist which give guidance for the realization of safety reports (see [1]).

Risk assessment methodology
In France there is no compulsory methodology for risk assessment. The operators are free to choose the methodology to use in their safety report. However, this methodology has to be appropriate and justified.

In the methodology used by INERIS in this study, the probability of each phenomenon is estimated by a semi-quantitative approach based on a specific on-site risk analysis performed by a group of experts involving the plant operators. A brief description of the methodology is given in Annex 2. This methodology allows site specific assessments.

In France, the operators also choose the models to use in order to determine the intensity of dangerous phenomena. The list of models used by INERIS in this study is given in Annex 2.

2.2 United Kingdom

Risk criteria

In case of a new development in the vicinity of a SEVESO II plant, the HSE will give an advice to the local authority. This advice will be based on calculations carried out by the HSE using their own software. Two different approaches are used for this LPG case: the protection based concept and the QRA for societal risk.

Protection based concept

For pressurised flammable gases HSE does not carry out quantified risk assessments for land use planning. HSE uses a protection based concept approach based on the hazard from the flammable substance. Three zones are calculated for a new hazardous substances consent application:

- inner zone (1800 tdu);
- middle zone (1000 tdu);
- outer zone (500 tdu).

Tdu = thermal dose unit. Units of $(kW/m^2)^{4/3}$.sec.

The zones (inner, middle and outer) are used in the process to assess planning applications for developments that may lie in those zones. Developments are categorized into four groups:

- category 1: People at work, parking areas;
- category 2: Developments for use by the general public – for example housing, hotels;
- category 3: Developments for use by vulnerable people – for example hospitals and schools;
- category 4: Very large and sensitive developments – for example large hospitals/schools and sports stadiums.

These are general definitions, and within each category there are further detailed descriptions (see [4] and [5]).

Having determined which zone the development falls into, and the category of the development, the following matrix is used to determine the type of advice.

Table 3 HSE matrix

Category	Development in inner zone	Development in middle zone	Development in outer zone
1	DAA	DAA	DAA
2	AA	DAA	DAA
3	AA	AA	DAA
4	AA	AA	AA

DAA = Don't Advise Against development AA = Advise Against development

Societal risk assessments

The QRA approach is used for the societal risk assessments, but the methods used are not currently employed other than for internal use. This may change in the future, because the societal risk and the criteria are under discussion in the United Kingdom[1].

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. For the societal risk two guide values are used: an upper and lower guide value. For this exercise HSE used the risk integral (RI) of 2000 for broadly acceptable risks (lower guide value), and 500,000 for intolerable risks (upper guide value) [6].

2.3 The Netherlands

Risk criteria

Two different measures are used in the Netherlands' QRA approach, namely individual risk and societal risk.

1. Individual risk represents the risk of an (unprotected) individual dying as a direct result of an on-site accident involving dangerous substances. Individual risk is visualized by risk contours on a map.
   The limit value for vulnerable objects is equal to $1x10^{-6}$ per year: no vulnerable objects are allowed within this 10^{-6} risk contour. For 'less vulnerable' objects (like small offices) the 10^{-6} contour is a target value.
2. Societal risk represents the risk of an accident occurring with N or more people being killed in a single accident. The societal risk is presented as an FN-curve.
   For the societal risk a guide value is used. The competent authority must account for the height of the societal risk in relation to socio-economic benefits.

Regulation

In 2004 the measures and criteria were implemented in the External Safety (Establishments) Decree [7] and obtained a legal status. Since January 2008, the guidelines for Quantitative Risk Assessment [8] and the software program to calculate the risks (SAFETI-NL) have also been prescribed by the External Safety Order [9].

QRA methodology

With the prescription of the guideline ('Reference Manual Bevi Risk Assessments' [8]) together with SAFETI-NL, QRA calculations for land use planning have been standardized and the results can be reproduced and are more robust and transparent. RIVM is responsible for the maintenance and development of the guideline and the software program SAFETI-NL.

The guidelines describe the standard method to perform a QRA. They give a well-defined set of scenarios (loss of containment events) for each type of installation, with a default failure frequency of each scenario. The modelling of the safety systems (e.g. emergency stop) is also largely standardized.
The scenarios are modelled with the software model SAFETI-NL. The user has to give characteristics like the material, amount and process conditions of the release, and also ignition sources, population and weather data. The effect models (calculating the release, dispersion and the different events (e.g. pool fire, jet fire, flash fire and explosion)) are fixed within SAFETI-NL. The

[1] The calculation of the societal risk for this benchmark study was performed in 2007. A survey of the discussions and reports since 2007 could be found at the website of the HSE: http://www.hse.gov.uk/societalrisk.

combination of the frequencies of the scenarios and the lethal effects, results in the individual risk and the societal risk. These risk results are the cumulative risks of all the scenarios together. The results are used in the land use planning and environmental permit approval.

2.4 Walloon Region – Belgium

First of all, it should be stressed that the land use planning policy is regional in Belgium, so each region (Flanders, Wallonia, Brussels) has developed its own methodology and regulations. The approach presented here is the one of the Walloon Region.

Risk criteria
The measure used to quantify the external risk due to SEVESO II plants is the individual risk. This is defined as the risk of an individual suffering irreversible damage due to an on-site accident involving dangerous substances. It is noted that the individual risk is not restricted to lethality.

The external risk is visualised by iso-risk contours around the SEVESO II plants. The societal risk is not taken into account.

Regulation
The land use planning around SEVSO II plants is mainly regulated in the 'Code Wallon de l'Aménagement du Territoire, de l'Urbanisme et du Patrimoine' (CWATUP) [10].

The area delimited by the 10^{-6} per year iso-risk curve is called the 'consultation zone', inside which the advice from the competent authority must be taken into account for every project concerning land use.

The maps are used by the competent authorities to issue or withhold building permits in the surroundings of the plant, so that neighbouring people are not exposed to an unacceptable risk. Authorities base their decision on a matrix adopted by the regional government, crossing the level of individual risk and the type of project for which the permit is applied for (industry, residential area, hospital, et cetera). In particular, it is interesting to note that a distinction is made between houses and vulnerable buildings like hospitals.

Table 4 Matrix for the decision-making process inside the consultation zone (Walloon Region, Belgium)

	Individual risk (risk of irreversible damage)		
	10^{-3} to 10^{-4} per year	**10^{-4} to 10^{-5} per year**	**10^{-5} to 10^{-6} per year**
Type A: Buildings and technical units directly linked with the geography *(catchment, water tower, wastewater treatment, windmill, et cetera)*	**OK**	**OK**	**OK**
Type B: Buildings for a few people, for the most part adult and autonomous *(workshop, logistic units, small shops, et cetera)*	**With caution**	**OK**	**OK**
Type C: Buildings for people, for the most part adult and autonomous, but without number restriction *(accommodation, workshops or offices for more than 100 people, schools and dormitories for students aged 12 and over, et cetera)*	**Not allowed**	**With caution**	**OK**
Type D: Buildings for susceptible people, with restricted autonomy *(hospitals, rest homes, schools and dormitories for children under 12, prisons, et cetera)*	**Not allowed**	**Not allowed**	**With caution**

QRA methodology
In the Walloon Region, the approach selected for the risk assessment and the determination of the consultation zones is similar to a full probabilistic approach, which is called a 'QRA' (Quantitative Risk Assessment). However, the approach chosen differs from a classic QRA method on several points, the most important one being that the risk is not expressed in terms of fatalities but is linked with the possibility of irreversible damage for people. The thresholds linked to the irreversible damage are: ERPG3 for toxic effects, 50 mbar for overpressure effects, and 6.4 kW/m² for thermal radiation. The frequencies used are generic ones, issued from the 'Handboek Kanscijfers 2004' of the Flemish competent authority [11].

In order to ensure the consistency of the QRA for all the SEVESO II plants located in the Walloon Region (90 establishments in 2008), the support of an external expert has been searched. The Major Risk Research Centre of the Faculté Polytechnique de Mons (FPMs) plays this role and calculates risk curves around the SEVESO plant. The recourse to only one expert for performing risk calculations offers the advantage of a common methodology and common assumptions for every SEVESO plant in the region. With the risk curves obtained, the Walloon Region draws the consultation zones on the local maps.

3 Description of the case

The detailed site description of the LPG plant is given in Annex 1.

At the LPG plant propane and butane can be unloaded from rail tank cars and road tankers and stored in vessels. The unloading facilities consist of rail tank cars for the delivery of propane and road tank cars for the delivery of both propane and butane. The storage farm includes two mounded cylindrical vessels for propane and one spherical vessel for butane. Finally, the loading facility contains road tank cars able to load both propane and butane.

Figure 1 shows the main installations of the LPG establishment.

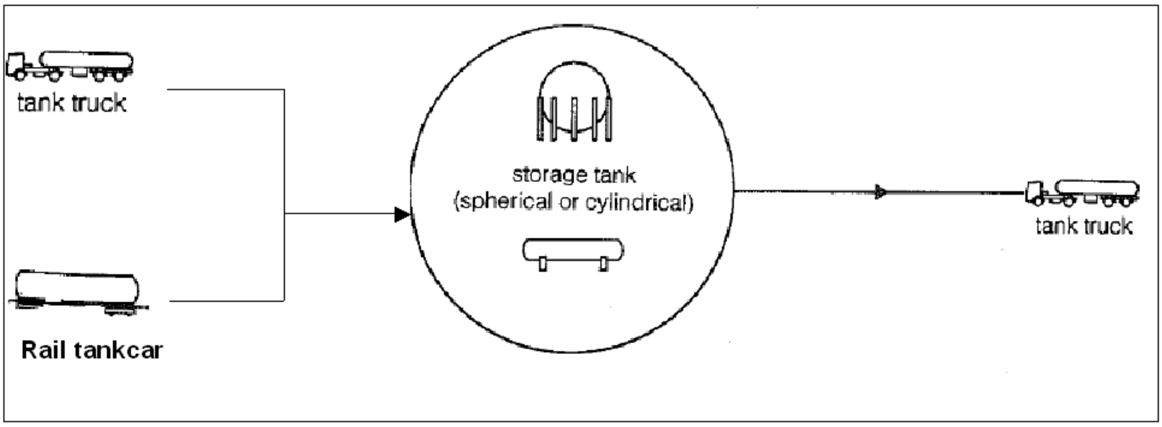

Figure 1 Illustration of the equipment that is considered in the LPG case

The LPG depot that is studied is based on:
- 2 cylindrical propane vessels in mounds with a capacity of 2500 m^3 per vessel;
- 1 spherical butane vessel with a capacity of 700 m^3;
- 3 rail tankcar unloading stations (2 unloading arms for each station: 1 for the liquid line and 1 for the vapour line);
- 2 road tanker stations: 1 loading station with 1 arm for propane and 1 loading/unloading station for both propane and butane with 2 arms (1 arm for the liquid line and 1 arm for the vapour line);
- a piping system equipped with:
  - 2 pumps for the road tanker loading station (propane);
  - 1 pump for the road tanker loading station (butane);
  - 1 compressor.

Further, safety valves are present at various locations and are connected to a gas detection system. More information has been written in Annex 1. A fictitious population has been defined in the surroundings of the facility in order to perform societal risks assessment and MMR matrix (see Annex 2). It is noted that the population case used isn’t realistic; the population has been spread in cells of 1 km^2 (density per km^2) and overlap the plant.

The four parties based their risk assessment on the same (technical) description of this fictitious plant, while they used their own methodology to perform the assessment.

4 Main results of the LPG case

The main results are described in this chapter:
- critical scenarios and dangerous phenomena;
- individual risk;
- societal risk;
- policy implications.

4.1 Critical scenarios and dangerous phenomena

This section gives an overview of the critical scenarios and phenomena of the four risk assessments. The selection was based on the contribution of the scenarios and phenomena to the individual and societal risks. The next table shows a summary of the main important scenarios of the four institutes.

Table 5 Overview of the main important scenarios

	UK	NL	F	Walloon Region
Propane vessel (mounded)				
BLEVE	significant for SR and outer zone			
Rupture		Significant for IR and SR		Significant for far zone
Butane vessel (aboveground)				
BLEVE	significant for inner and middle zone	Significant for IR and SR		Significant for IR in far zone
Rupture		Significant for IR and SR		Significant for far zone
Pump				
Rupture				Significant for middle zone
Pipe				
Rupture			Most significant	
Transshipment				
Rupture (un)loading arm			Most significant	Significant for nearby zone

It can be seen that the relevance of specific scenarios varies highly between the different methodologies. This is a clear indication that the methods differ significantly.

4.1.1 France

Based on the risk matrix (Table 13), the most critical dangerous phenomena are the following:
- dangerous phenomena related to road tanker loss of containments;
- dangerous phenomena related to rail tank cars loss of containment;
- dangerous phenomena related to 6” pipe loss of containment.

The details of these phenomena are given in the next table. The numbering of the phenomena can be found in Annex 2.

Table 6 INERIS – Disastrous phenomena with highest probability

N°	Dangerous phenomena description	Pro-ba-bility	Sign. Let. effects (distance for 5% lethality)	Let. effects (distance for 1% lethality)	Irrever-sible effects	Severity Category
2	jet fire on road tanker transshipment post: Loss of containment on loading/unloading arm: Full bore rupture – With isolating system (20 s)	D	155 m	175 m	195 m	Disastrous
6	Flash fire on road tanker transshipment post: Loss of containment on loading/unloading arm: Full bore rupture – With isolating system (20 s)	D	170 m	170 m	190 m	Disastrous
30	jet fire on piping system: Loss of containment on pipe (6"): Full bore rupture – With isolating system	D	175 m	190 m	195 m	Disastrous
34	Flash fire on piping system: Loss of containment on pipe (6"): Full bore rupture – With isolating system	D	180 m	180 m	200 m	Disastrous

4.1.2 *United Kingdom*

A hazard calculation has been made using the HSE model FLAMCALC6 to provide a protection based assessment (see Annex 3).

Table 7 HSE calculations

Vessel	Substance	Capacity (m^3)	Distance from vessel boundary (m)		
			Inner zone (1800 tdu)	Middle zone (1000 tdu)	Outer zone (500 tdu)
Collection road car	Propane	47	100	137	186
Delivery road car	n-Butane	47	109	148	200
Delivery railcar	Propane	119	159	210	282
Mounded vessel	Propane	2500	mounded	mounded	901
Surface sphere	n-Butane	700	283	379	509

The only scenario taken into account in this approach is the BLEVE. Because the propane vessels are mounded, the inner and middle zones are not calculated. The HSE policy is to consider the BLEVE of the mounded vessel for the outer zone. Consequently, the mounded propane vessel and the butane vessel are the main scenarios for the protection based concept.

For the societal risk calculations the following scenarios have been considered:
- BLEVE from vessels and tankers;
- releases from pipework resulting in flash fires and jet fires;
- coupling releases resulting in flash fires and jet fires;
- instantaneous and continuous releases from the butane sphere resulting in flash fires.

For the societal risk (N >100) the BLEVE of the mounded propane vessels determines the FN-curve. The BLEVE of the mounded vessels is considered in the calculations (in contrast to the protection based concept), but with a reduced failure frequency (by a factor 10).

4.1.3 The Netherlands

In the Dutch QRA approach scenarios (loss of containments) are modelled and the risk software SAFETI-NL calculates the different event probabilities and consequences (such as BLEVE, explosion, flash fire) based on a standardized event tree. For an overview of all the scenarios see Annex 4.

The main scenarios (main contribution to the calculated risks) in the LPG case are related to the vessels of butane and propane.

Table 8 Main scenarios RIVM

Risk	Main scenarios
Individual risk (IR 10^{-6})	Butane vessel – Instantaneous release Propane vessel – Continuous release of the complete inventory in 10 min Propane vessel – Instantaneous release
Societal risk (for N >100)	Butane vessel – Instantaneous release Propane vessel – Instantaneous release

Analysing the main events (phenomena) of the three main scenarios, gives the following effect distances.

Table 9 Main phenomena and effect distances (RIVM)

Main scenarios	Phenomena	Effect distance (m)
Butane vessel – Instantaneous release	Flash fire (LFL) BLEVE (35 kW/m^2)	850 280
Propane vessel – Continuous release of the complete inventory in 10 min	Flash fire (LFL)	620
Propane vessel – Instantaneous release	Flash fire (LFL) BLEVE (not considered: mounded vessel)	500 -

4.1.4 Walloon Region – Belgium

The software used (Phast Risk 6.53.1) allows to define 'risk ranking points', which means locations where the main scenarios contributing to the risk are identified. Every 100 m, left and right of the centre of the plant (storage) 5 points were defined. Detailed results are shown in Annex 5.

The main conclusions are:

- At shorter distance of the installations (located on point 0 m), the main contributing scenario is the full bore rupture of the unloading arm of the rail tank car.
- At middle distance (between 200 and 400 m), the catastrophic rupture of the pump is the main contributor to the risk (this scenario is important because its frequency is rather high and the breach diameter is large: 250 mm).
- At longer distance (between 300 and 500 m), the catastrophic rupture of the butane storage (including the BLEVE) and, in a lesser extent, the catastrophic rupture of the propane storage (without BLEVE) are predominant.

4.2 Individual risk

This section gives an overview of the individual risk results. The table below shows a summary of the most relevant safety distances for policy decision-making of the four institutes. Section 5.3 gives the limit and guide values and the policy implications of these results.

Table 10 Individual risk results

	Value	**Distance (m)**
France	Aléa VH (expropriation)	274
United Kingdom	Inner zone (houses)	280
	Middle zone (schools, hospitals,…)	380
Netherlands	IR 10^{-6} per year (limit value)	250
Belgium (Walloon Region)	IR 10^{-5} per year (houses)	200
	IR 10^{-6} per year (schools, hospitals,…)	375

4.2.1 France

The next figure shows the map of the synthesis of aléas calculated by INERIS.

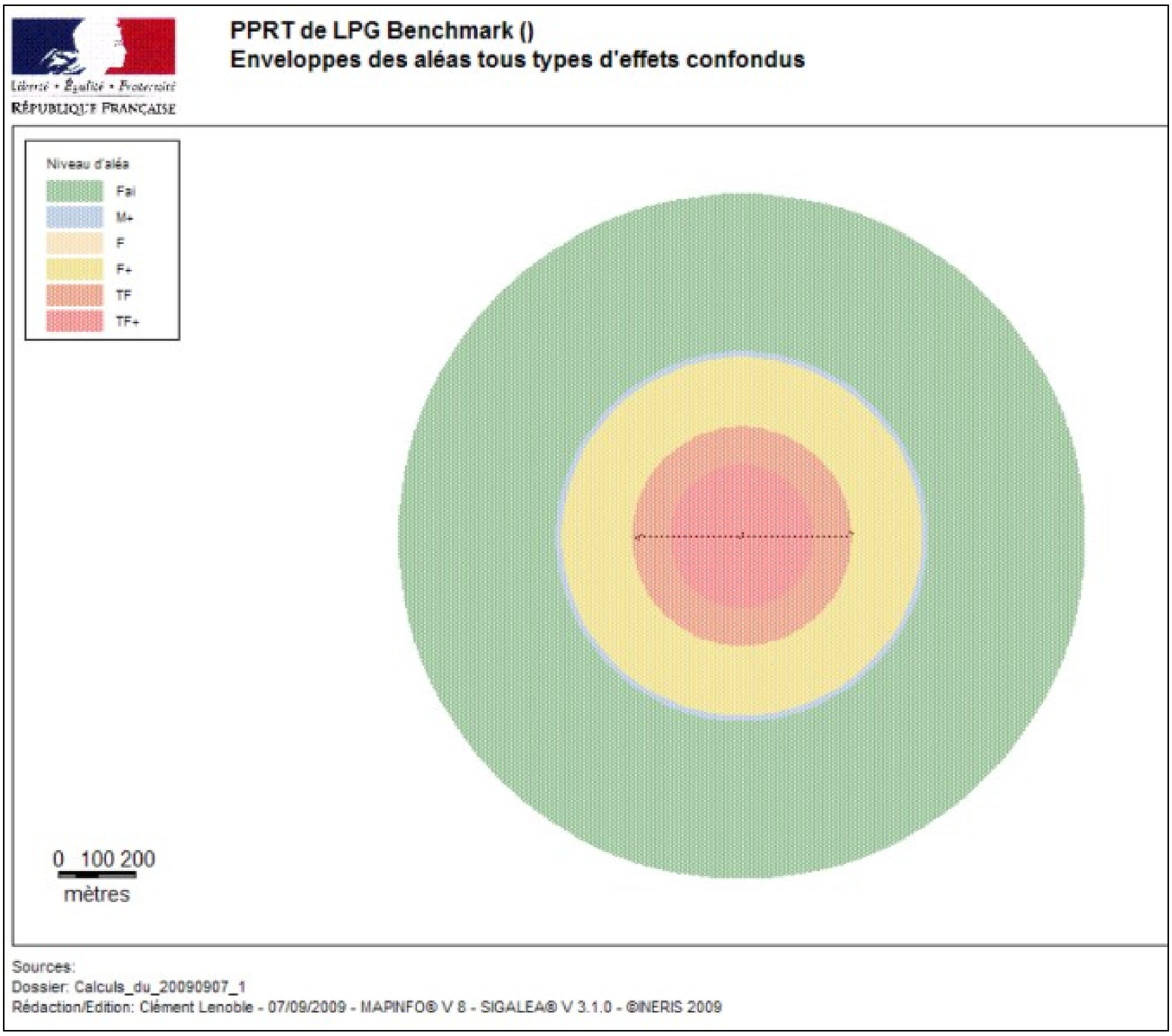

Figure 2 Map of the synthesis of aléas (INERIS)

Examples of criteria for housing (see section 2.1):

- red zones (VH+/VH): the risk is not acceptable and expropriation is possible;
- yellow/orange zones (H+/H): the risk will be not acceptable in the longer term and relinquishment is possible;
- red zone and yellow zone (VH+/VH/H+/H): no new construction allowed or specific conditions to the new construction are required.

The distances (radius in meters) are given in the next table.

Table 11 Distances related to aléa zones (INERIS)

Aléa zones	Distance (m)
VH+	180
VH	274
H+	450
M+	464
Low	860

Detailed information on dangerous phenomena which have been taken into account in order to realize the aléa map is given in the Annex 2.

4.2.2 *United Kingdom*

The figure below shows the three zones calculated by HSE.

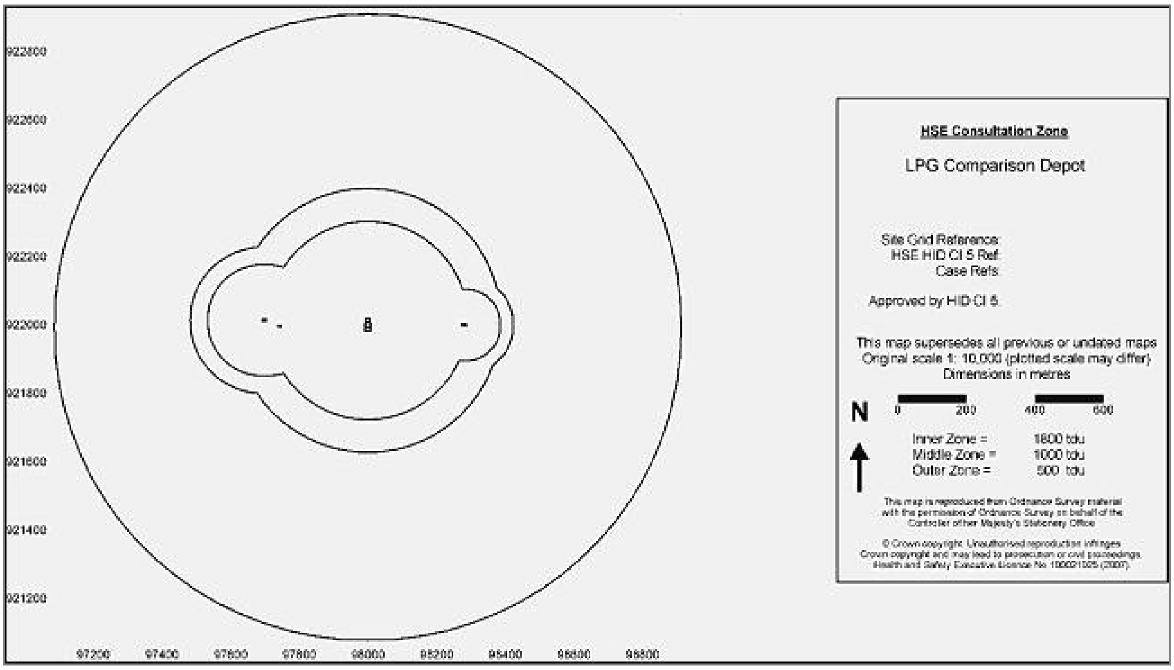

Figure 3 Land use planning zones (HSE)

The distances (radius in meter) are:

- inner zone (1800 tdu): 280 m;
- middle zone (1000 tdu): 380 m;
- outer zone (500 tdu): 900 m.

HSE modelled the equipment at three different locations: the delivery area in the west side, the vessels at the centre and the collection area in the east side. INERIS and RIVM modelled all the equipment at one single point.

4.2.3 *The Netherlands*

The next figure shows the individual risk contours calculated by RIVM.

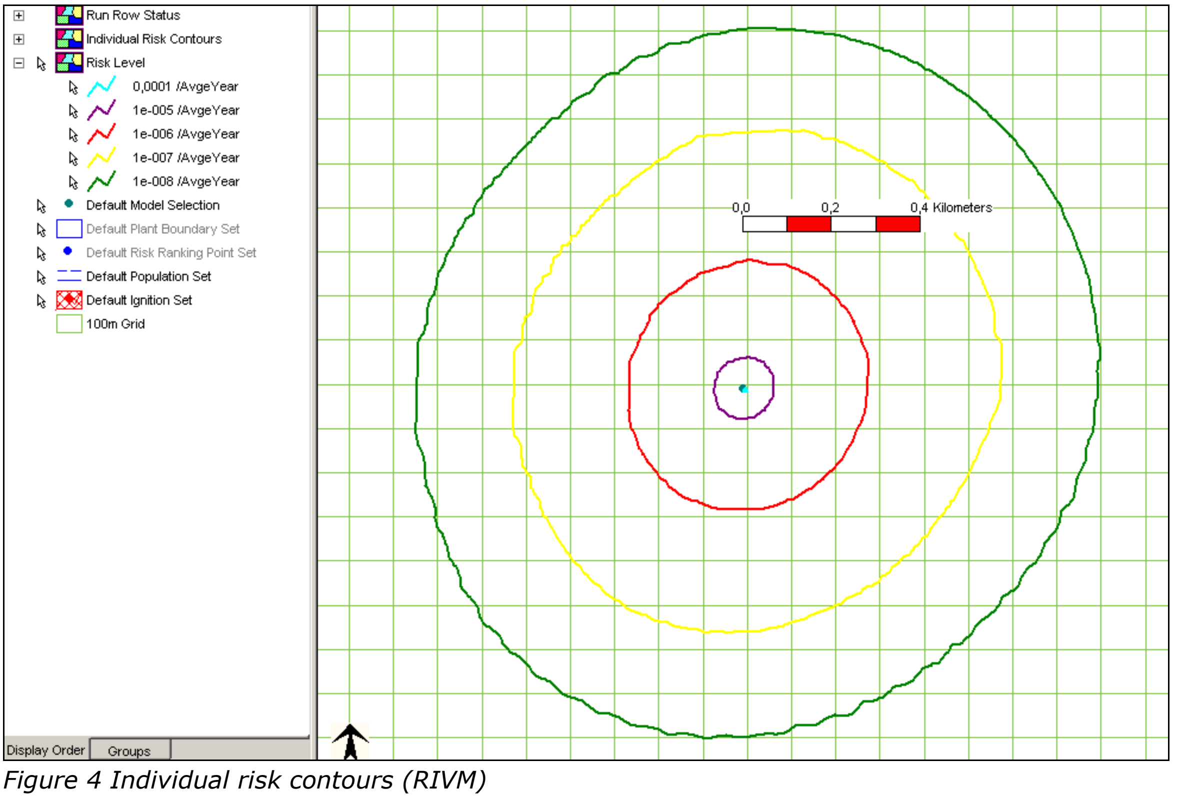

Figure 4 Individual risk contours (RIVM)

The red contour is the limit value of 10^{-6} per year.

The distances (radius in meter) are:
- IR 10^{-6} per year (red contour): 250 m;
- IR 10^{-7} per year (yellow contour): 550 m;
- IR 10^{-8} per year (green contour): 770 m.

4.2.4 *Walloon Region – Belgium*

FPMs calculated the risk of the LPG case for two cases:
- case A: all the equipment is located on the same spot;
- case B: equipment is located along a line.

For the comparison just the results of case A are given. The whole QRA including case B can be found in Annex 5.

Figure 5 shows the iso-risk contours of case A. The 10^{-6} /y curve, which is the outer limit of the consultation zone, is red coloured. Inside the area delimited by the light blue line (10^{-5} /y), no houses are allowed. The hatched area indicates the zone where delayed ignition could take place (input data).

The maximum distances to the iso-risk curves (distance between the centre of the plant and the curve) are given in the next table.

Table 12 Land use planning distances in Walloon Region (Belgium)

Iso-risk curves	**Maximum distance between the centre of the LPG plant (location of the storage vessels) and the curve (in m)**
	Case A
10^{-5} /y (max. individual risk for houses and type C buildings)	200
10^{-6} /y (max. individual risk for hospitals, schools and type D buildings)	375

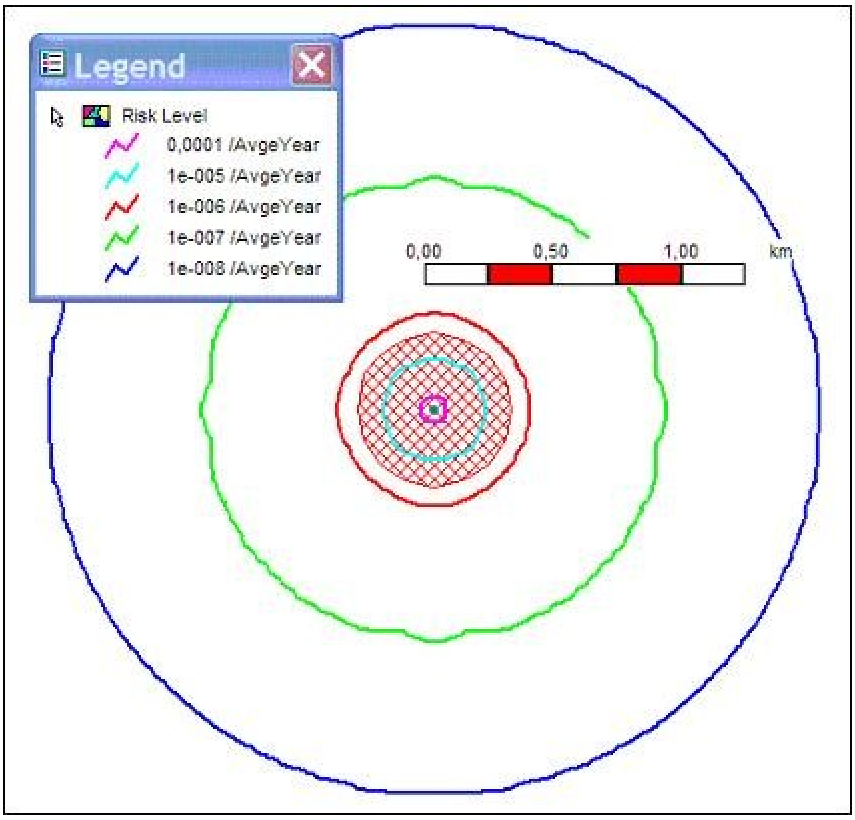

Figure 5 Iso-risk curves for the LPG plant (case A)

4.3 Societal risk

In this section the results of the societal risk calculation are shown. In France the MMR matrix is used. Four accidents are in the 'unacceptable' area of the matrix.
Both the Netherlands and the United Kingdom calculated an FN-curve. The curve of RIVM exceeds the guideline, while the HSE curve does not exceed the guideline. In section 5.4 the comparison of the two FN-curves together with the two guidelines is made.
Societal risk is not considered in the Walloon Region.

4.3.1 *France*

The following table shows the MMR matrix for the case of the fictive LPG depot. The severity of a scenario depends on the number of people exposed to the various intensity levels (see Annex 2). It is noted that the definition of population for this fictitious case was very sketchy. That's why the outcomes of the MMR matrix are not indicative for realistic depots.

Table 13 MMR matrix for the fictive LPG depot

Probability **Severity**	**E**	**D**	**C**	**B**	**A**
Disastrous	1 - 5 – 10 -14 - 18 – 23 – 24 - 27 -28 – 29 – 33 – 35	2-6-30-34			
Catastrophic	19 – 25	7 -9 -11- 15 -16 -17			
Significant	3 – 12 -26 -31	4 -8 -32			
Serious					
Moderate					

The numbering of the phenomena can be found in Annex 2.

The matrix shows that four accidents are in the 'unacceptable' area of the matrix. These accidents concern road tankers, rail tankers and 6" pipes (see Table 6). Detailed information on accidents considered in the framework of this study is given in Annex 2. The consequences for the delivery or continuation of the permit will be discussed in section 4.4.

4.3.2 *United Kingdom*

The societal risk calculations have been carried out using HSE spreadsheet tools – a development tool at present. The figure below shows the societal risk curve. The X-axis represents the number of fatalities and the Y-axis corresponds to the cumulative frequency (per year) of all the scenarios together. For the scenarios see Annex 3.

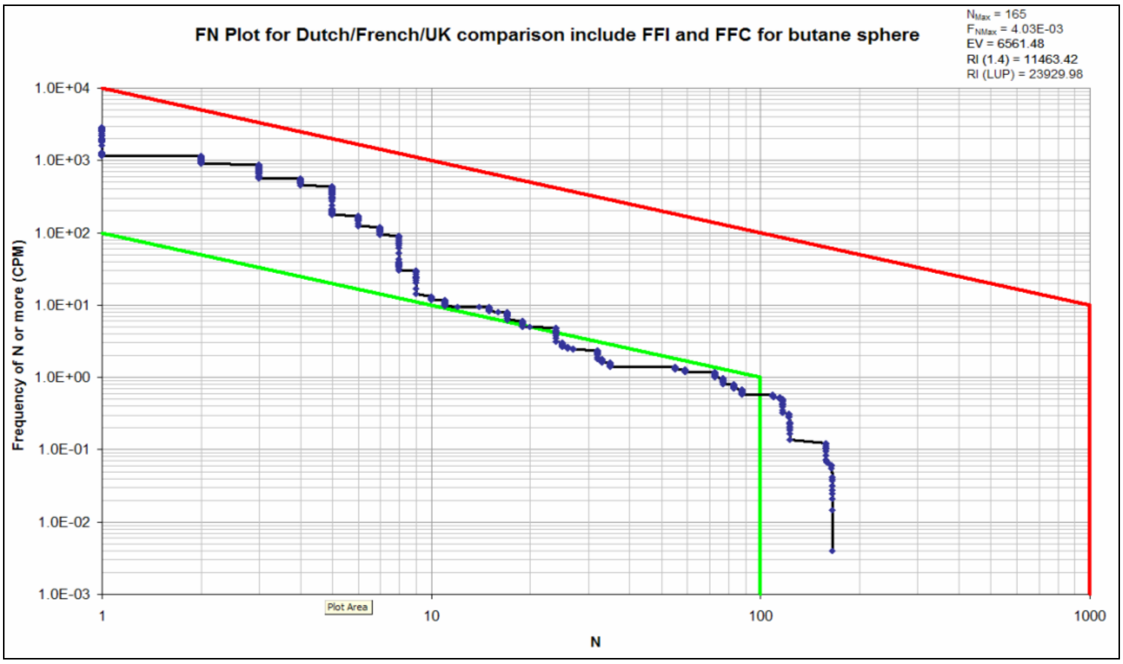

Figure 6 Societal risk (HSE)

As indicated in section 2.2 the societal risk doesn't have official relevance and is only for internal use. The red line is the criterion for 'intolerable' risks and the green line for broadly acceptable risks.
The risk integral (RI) is 11,463 (compared to the criteria of RI = 2000 for broadly acceptable risks and RI = 500,000 for 'intolerable' risks).

Nmax = the maximum number estimated to be possibly killed = 165.

4.3.3 *The Netherlands*

The figure below shows the societal risk curve. The X-axis represents the number of fatalities and the Y-axis corresponds to the cumulative frequency (per year) of all the scenarios together (see Annex 4).

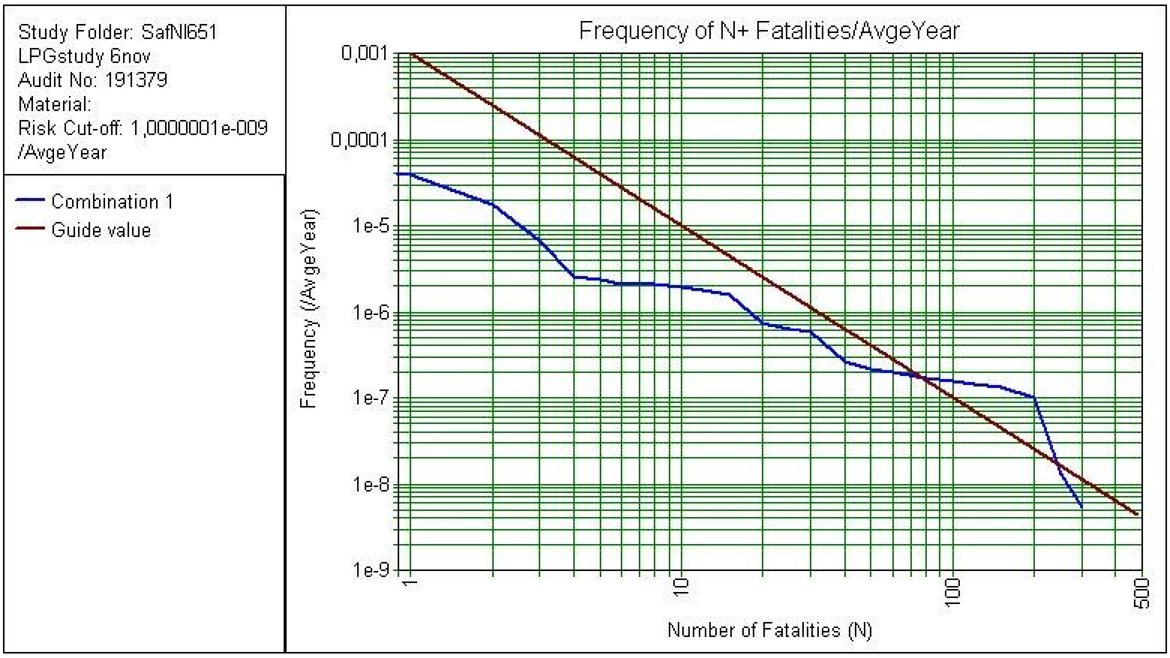

Figure 7 Societal risk (RIVM)

The red line is the guide value of the societal risk. Between N = 100 and 250 the guide value is exceeded.

4.3.4 *Walloon Region – Belgium*

The societal risk is not considered in the Walloon approach.

4.4 Policy implications

4.4.1 *France*

Considering the results of the approaches, the authorities may propose the following recommendations for this fictive case:

- MMR matrix (societal risk): the risk is unacceptable because of the following elements:
    - there are accidents in the 'unacceptable area';
    - there are more than 5 accidents in the 'ALARP class 2' areas.

As a consequence, the authorities will ask the operator of the plant to implement new safety measures in order to reduce the risk related to these accidents. This concerns mainly delivery operations and the 6" pipe.

- PPRT: For dwellings, the conclusions of the PPRT could be the following:
    - in a radius of 274 m expropriation is possible;
    - in a radius of 450 m relinquishment is possible;
    - it is likely that new constructions would be forbidden in a radius of 450 m around the facility;
    - in a radius of 860 m, some restrictions and limitations may be applied to new constructions.

However it has to be underlined that the situation is considered as unacceptable at the level of the MMR matrix. Therefore, new safety measures have to be implemented in the plant. It is likely that these new safety measures would have a significant impact on the aléa levels: the highest risk aléa zones would be less extensive.

4.4.2 *United Kingdom*

The government's conclusions of the fictitious LPG plant are based on the results of the risk calculations:

- Protection based concept:
  An existing situation will be allowed. When someone wants to build in one of the three zones (inner, middle and outer) the advice (positive or negative) depends on the category of development related to this zone.
    - Developments for the use of the general public – for example housing – within the inner zone of 280 m will receive a negative advice. If these developments would take place in the middle or outer zone the advice will be positive.
    - Hospitals and schools will be advised against in the inner and middle zones (380 m), and will not be advised against in the outer zone at a distance of more than 380 m.

- Societal risk:
  The FN-curve doesn't exceed the criterion for 'intolerable' risks (red line) and therefore there's no problem. The risk integral (RI) is 11,463 (compared to the criteria of RI = 2000 for broadly acceptable risks and RI = 500,000 for 'intolerable' risks). It is noted that the societal risk isn't used in the formal decision making process.

4.4.3 *The Netherlands*

The government's conclusions of the fictitious LPG plant are based on the results of the risk calculations:

- Individual risk:
  The limit value for vulnerable objects (houses, hospitals, schools) is equal to 1×10^{-6} per year: no vulnerable objects are allowed within this 10^{-6} risk contour (250 m).
- Societal risk:
  For the societal risk a guide value is used. This guide value is exceeded and the societal risk should be seriously taken into account in the decision-making process [7]. Technically, the situation could be refused based on the account of the societal risk. However, in practice, the account of the societal risk will probably lead to additional requirements concerning the emergency plans. The competent authority must account for the societal risk and can e.g. include emergency response plans.

If there are buildings (houses) within the 10^{-6} risk contour (250 m) the situation is not allowed. If this is not the case, the authority should account for the height of the societal risk.

4.4.4 *Walloon Region – Belgium*

The policy conclusions are based on the matrix presented in section 2.4 and the position of the calculated iso-risk curves.

In summary, the situation is allowed if:

- there is no type C object (e.g. houses) inside a 200 m distance;
- there is no type D object (like hospitals, schools) inside a 380 m distance;

- there are also criteria for buildings type A and B, linked to the position of 10^{-3} /y and 10^{-4} /y iso-risk curves.

The above-mentioned distances are calculated starting from the centre of the plant. The societal risk is not quantified.

5 Discussion

This chapter describes the similarities and differences of the four risk assessments based on the results of the LPG case. In the first section the differences of the QRA approaches are shown. Then a comparison is given of the calculated effect distances, the risk results and finally the policy implications of these results.

5.1 QRA approaches

The four QRA approaches use scenarios with failure frequencies and the calculation of effect and risk distances. This comparison study shows the differences within these approaches:

- In France there is no compulsory methodology for risk assessment. INERIS uses bow ties analyses to assess the accidents considered and the results are shown in a risk matrix. The approach is labelled as semi-quantitative. The probability used in the matrix is the result of expert judgment and is expressed as a frequency range. For consequences, five intensity levels are distinguished. The MMR matrix shows the risk per accident (based on exposed people). The seven different aléa zones that are distinguished are used for land use planning.
- In case of a new development in the vicinity of a SEVESO plant, the HSE will give an advice to the local authority. This advice will be based on calculations carried out by the HSE using its own software. For this LPG case HSE used a consequence based approach (protection based concept) for the land use planning. This results in the definition of three zones, on the basis of BLEVE scenarios (with a 50% capacity). The mounded propane vessels are excluded. The QRA approach used for the societal risk calculations (different scenarios with generic frequencies) is a risk based approach, but the societal risk doesn’t have an official status.
- In the Netherlands the QRA calculations for land use planning have been standardized, based on prescribed guidelines. RIVM is responsible for the management and development of the guidelines and the software program. The guidelines give a set of scenarios with a default failure frequency of each scenario. Both individual risk and societal risk are based on lethality. The Dutch QRA is a risk based approach.
- In the Walloon Region, FPMs determines the individual risk using a probabilistic approach. The risk is not expressed in terms of fatalities but is linked with the possibility of irreversible injury for people. The methodology imposes a set of scenarios with generic failure frequency. The influence of protective safety systems (downstream of the loss of containment) is taken into account to determine the frequency of each phenomenon. The societal risk is not taken into account.

5.2 Dangerous phenomena and effect distances

The results of the four risk assessments as described in section 4.1 show differences in the scenarios (accidents) and effect calculations.

The main scenarios contributing to the risks show differences. In France the storage vessels of propane and butane are not considered when mounded or when some specific conditions related to safety are fulfilled. The (un)loading activities are predominant. In the United Kingdom and the Netherlands the vessels dominate the risk results. This is an example of the different selection of scenarios.

Further, the selection of phenomena shows differences. For example, in the Netherlands and the Walloon Region a BLEVE of the propane vessels is not considered, because the vessels are mounded. However, HSE takes the BLEVE of the mounded vessels into account.

To get more insight in the differences the effect calculations of the BLEVE of the butane sphere (700 m^3) and the flash fire (cloud + delayed ignition) of the mounded propane vessel (2500 m^3) or the propane pipework were analysed.

5.2.1 *BLEVE of the sphere butane (700 m^3)*

The next table shows the results of the BLEVE of the butane vessel.

Table 14 BLEVE of the butane vessel

	UK	**NL**	**F**	**Walloon region**
Filling ratio considered for BLEVE	LUP: 50% SR: 100/75/50/25%	Based on site description: For butane 55%	85%	Based on site description: For butane 55%
Lethal threshold	LUP: 500-1000-1800 tdu SR: LD1, LD10, LD50	Probit of heat radiation (35 kW/m^2 is 100% lethal)	600-1000-1800 tdu	Dose for risk effects: 2.376E6 $(W/m^2)^{4/3}$.s 6.4 kW/m^2 during 20 s (irreversible effect)
Model	HSE internal	Phast (DNV)	INERIS internal	Phast (DNV)
Distances obtained in the benchmark for the sphere	1800 tdu 283 m 1000 tdu 380 m 500 tdu 510 m	For BLEVE butane with burst pressure of 12 bar(g) L10% 600 m L3% 670 m L1% 720 m	1800 tdu 330 m 1000 tdu 460 m 600 tdu 590 m	For BLEVE butane with burst pressure of 9.7 bar(g) Dose reached at 890 m (920 m for a burst pressure of 12 barg)

LUP: land use planning; SR: societal risk; LD: lethal dose; L%: percentage lethality

The largest distances of the BLEVE are between 380 and 920 m. Based on the analysis of the effect calculations, differences in modelling and thresholds arise.

Modelling:

- The four parties use different burst pressures for the BLEVE calculations. For example, INERIS uses 6.5 bar(g) and RIVM 12 bar(g).
- With regard to the amounts of butane, HSE and INERIS have deviated from the site description.
- Both INERIS and HSE calculate the effect distances with a home made software tool. FPMs and RIVM use Phast (Risk) of DNV Software.
- Because FPMs and RIVM use the same software and the same input parameters (amount, burst pressure) for the BLEVE, the difference of the

calculated effect distances for the BLEVE of butane is caused by the thresholds used.

Thresholds:

- For the BLEVE, RIVM uses a probit relation of heat radiation with the lethality level of 1% as the end point of the calculations:

  $$Pr = -36.38 + 2.56 \ln (Q^{4/3} \times t);$$

  with heat radiation Q in kW/m^2 and duration t in seconds [8].

  Based on a duration of 20 seconds, the lethality level of 1% is equal to the heat radiation of 9.8 kW/m^2.
- FPMs uses a heat radiation level of 6.4 kW/m^2 during 20 seconds as the end value for the irreversible effect of the BLEVE. This level is equal to a lethality level of 0.01% using the Dutch probit relation.
- Both HSE and INERIS use three levels of the thermal dose to determine the effect distances. HSE calculates the distances related to 500, 1000 en 1800 tdu (thermal dose unit in $(kW/m^2)^{4/3}$.sec) and INERIS uses 600, 1000 and 1800 tdu. So the end points of the calculations differ (500 and 600 tdu). In addition, 500 tdu relates to a lethality level of 3% based on the Dutch probit relation. The dose of 600 tdu relates to a lethality level of 7.5%.

5.2.2 *Flash fire of the mounded propane vessel (2500 m^3)*

The next table shows the results of the flash fire of the propane vessel.

Table 15 Flash fire propane vessel

	UK	**NL**	**F**	**Walloon Region**
Amount considered	100% (vessel)	85% Flash fire for vessel	85% (vessel) Flash fire for 10" pipe (limited drift)	85% (2125 m^3) Flash fire for vessel
Lethality threshold	LFL	LFL	LFL	LFL
Model	HSE internal	Phast (DNV)	INERIS internal	Phast (DNV)
Effect distance in the benchmark study : propane	550 m	500 m	500 m (irrev effects), 450 m (lethal effects)	655 m

Based on the analysis of the effect calculations, differences in modelling arise:

- With regard to the amounts of propane, HSE has deviated from the site description and uses its own standards. This means a volume of 100% for the flash fire of propane, instead of a volume of 85% for propane vessel from the site description.
- Because INERIS doesn’t consider the mounded propane vessel, the effect distance is based on the flash fire of a 10” pipeline.
- Both INERIS and HSE calculate the effect distances with a home made software tool. FPMs and RIVM use Phast (Risk) of DNV Software.
- Because FPMs and RIVM use the same software, the same amount and the same threshold (LFL) for the flash fire the difference of the calculated effect distances of the flash fire is caused by the way of modelling the scenario in Phast Risk. The distance of 500 m is based on the instantaneous release of propane, while a release of the propane within 10 minutes results in an

effect distance of 620 m (see Table 9). This shows that the use of the same software program not automatically leads to the same results.

5.2.3 Summary of comparison of effect distances

In summary, the differences in effect distances can be explained by modelling differences (% of volume, process conditions, burst pressure of the BLEVE, parameters and software) and retained thresholds.

The thresholds (end of calculation) differ from the dose for irreversible damage (FPMs), the probit relation of heat radiation (RIVM) to the level of heat radiation used (different levels used by HSE and INERIS). These differences are also related to the different scope of the calculations. HSE and RIVM calculate the risk of people dying as a result of loss of dangerous materials. INERIS calculates the risk of people exposed to several predefined levels of intensity. In the Walloon Region, the risk is linked with the possibility of irreversible injury.

The differences in the distances of the BLEVE are much bigger than the differences in the flash fire calculations. Probably the calculation of the flash fire is less sensitive to input parameters and the flash fire has been calculated with a single end value (LFL).

5.3 Individual risk

The table below shows the most important risk distance (i.e. the distance related to vulnerable objects/residences) of the four institutes.

Table 16 Individual risk results

	Value	**Distance (m)**
United Kingdom	Inner zone (1800 tdu)	280
France	Aléa VH	274
Netherlands	IR 10^{-6} per year (limit value)	250
Belgium (Walloon Region)	IR 10^{-5} per year (limit value for houses)	200
	IR 10^{-6} per year (limit value for schools, hospitals,…)	375

The distances are of equal dimensions. This similarity of the results is remarkable, considering the large differences in the methodologies, and is considered to be largely coincidental.

5.4 Societal risk

The societal risk calculated by HSE and RIVM results in an FN-curve. Both curves with the guidelines are shown in the figure below.

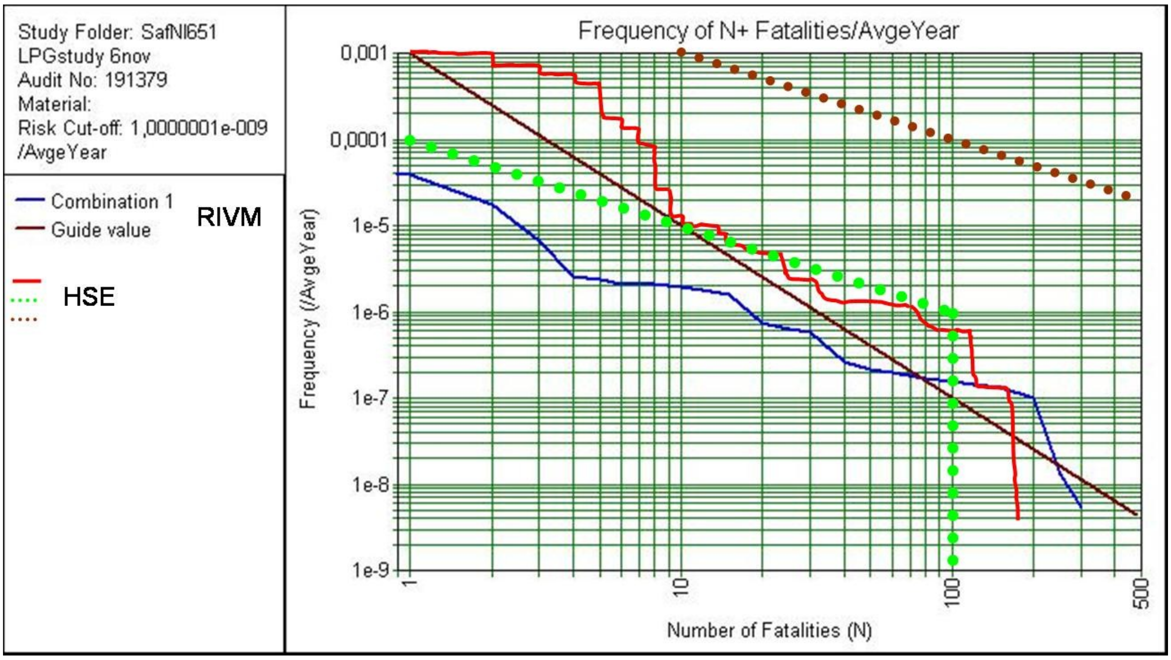

Figure 8 Societal risk of RIVM and HSE together

Explanation:
- RIVM: blue curve (with line guide value);
- HSE: red curve (with dotted guide values).

The HSE FN-curve (red) is larger than the RIVM curve (blue); there is approximately a factor 10 of difference in frequencies. Moreover the figure shows that the guide value of RIVM (line) is stricter than the dotted line of HSE. The conclusion is that in the Netherlands the societal risk exceeds the guide value and in the United Kingdom the societal risk is considered acceptable.

The MMR matrix (which can be compared to societal risk) of INERIS shows that four phenomena are in the 'not acceptable' zone of the matrix. This case would not be tolerated in France. Additional risk reduction measures will have to be implemented.

5.5 Policy implications

For this fictitious LPG case the following government's conclusions are made:

France
This case should not be authorized. There are accidents in the 'unacceptable' areas of the MMR matrix and one of the cells in the 'ALARP-2' area has more than 5 accidents. Additional safety measures should be implemented.

United Kingdom
The existing situation will be allowed by the HSE. The development of housing (land use planning) will be advised against in the inner zone. The FN-curve doesn't exceed the criterion for 'intolerable' risks (red line) and therefore the societal risk is acceptable (in spite of the fact that the societal risk isn't used in the formal decision-making process at all).

The Netherlands
If there are buildings (houses) within the 10^{-6} risk contour the situation is not allowed. If this is not the case, the authority should account the size of the societal risk. In this case the guide value of the societal risk is exceeded and therefore the competent authority will pay serious attention to account for the situation and can e.g. demand sophisticated emergency response plans.

Walloon Region (Belgium)
If there are buildings of type C (such as houses) within the 10^{-5} risk contour or if there are buildings of type D (such as schools) within the 10^{-6} risk contour the situation is, in theory, not allowed (it can be allowed in some cases with caution).

6 Conclusions

In this report a comparison is made of the Quantitative Risk Assessment (QRA) methods used in the United Kingdom, France, the Netherlands and the Walloon Region of Belgium. In order to compare the different approaches a benchmark exercise was performed for a fictitious LPG plant. INERIS from France, the Health and Safety Executive (HSE) from the United Kingdom, RIVM from the Netherlands and the Faculté Polytechnique de Mons (FPMs) from Belgium used their own QRA approaches to describe the different scenarios and dangerous phenomena and to calculate the risks.

The most important conclusions of this benchmark are summarised below:

Methodologies

1. The INERIS approach is a (semi-quantitative) risk based approach. The bow tie analysis is useful for analysing the safety measures of a company in detail. The results of the assessment can be used to improve the process safety of a plant and to implement reinforcements to construction around the plant.
   To define the frequency of dangerous phenomena expert judgments can be used in France. Objectivity proves to be an issue here. Furthermore every risk assessment is specific and not generic.
2. The English consequence based approach for flammable materials is the protection based concept (for land use planning). Hereby only the BLEVE is considered and that makes the approach easier than a complete QRA. This gives a generic approach.
3. The Dutch QRA approach is generic and standardized, because of the use of the QRA results for land use planning decisions. For this reason, it has been decided to use a robust and transparent QRA method in the Netherlands. Consequently, the QRA of a company A is based on the same initial failure frequencies and scenarios and modelled with the same software as the QRA of a company B.
4. The Walloon Region also uses a generic approach (consideration of a list of scenarios with generic frequency associated). In the Walloon Region, the QRA takes into account the specificity of each site by considering the protective safety systems (downstream of the loss of containment).
5. The four methodologies show a difference between robust, generic (standardized) methods on one side and specific methods based on expert judgment on the other side. The choice of a ‘generic’ method (in the Netherlands, the Walloon Region and the United Kingdom) means that the QRA is not suitable for analysing risk reducing measures in detail (therefore a specific approach (like the French approach) is needed). But a generic QRA method makes the QRA more transparent and robust. Further, the use of a generic QRA method doesn’t mean a subsequent analysis is not possible at all. It is possible to see if the risks can be mitigated for example by reducing the risks of the most contributing scenarios (e.g. reducing the amount, relocation of an activity).

Calculation and results

1. The benchmark study shows that the dominant scenarios are very different. The scenarios of the propane vessels are important for HSE, RIVM and FPMs, while INERIS doesn't consider the mounded propane vessel at all (which is allowed if some norms are applied). Further, the analysis of the effect calculations of the BLEVE and the flash fire demonstrates the differences in modelling, software and thresholds between the four parties.
2. There are differences in the thresholds (end of calculations) used. HSE and RIVM calculate the risk of people dying as a result of loss of dangerous materials. INERIS calculates the risk of people exposed to several predefined levels of intensity. In the Walloon Region, the risk is linked with the possibility of irreversible injury. This leads to different effect distances.
3. The four parties calculate safety distances that are used in the land use planning. Because of the different approaches and effect calculations, the similarity in the calculated risk distances for residences (between 200-280 m) is surprising.
4. The MMR matrix in France shows the risk level of each scenario. This matrix is used for the delivery of the permit. In this benchmark four scenarios were considered as 'unacceptable´. In the Netherlands a societal risk (FN-curve) is calculated and in the benchmark the guide value is exceeded. In the Walloon Region the societal risk is not taken into account and the societal risk doesn't have an official status in the United Kingdom. Only for this benchmark HSE calculated an FN-curve. This curve is larger than the RIVM curve, but the guide value of HSE is less strict than the Dutch guide value and the FN-curve of the HSE is considered acceptable. This means that there is a lot of variation in the way the countries take societal risk into account.

Policy implications and guide values

1. In the four countries the decision of the situation depends on the question if the development of buildings takes place within the safety distances. In France and the Netherlands a limit value is used; in the United Kingdom and the Walloon Region the safety distances are used to give an advice. This means that, given an unacceptable situation, the risks must be reduced if a limit value is used. In case of an advice, it depends on the local authorities whether the risks will be accepted (against the advice) or the risks must be reduced.
2. The French MMR matrix is more restrictive than the FN-curve of the RIVM and is used as a go/no go decision tool. If phenomena appear in the 'not acceptable cells' in the MMR matrix, the situation will not be allowed and additional safety measure will be required. When the guide value of the FN-curve is exceeded, the Dutch authority must account for the height of the societal risk. The outcome is uncertain. Technically, the situation could be refused, but in practice, the account of the societal risk will probably lead to some additional requirements.
3. The Walloon Region QRA approach does not take the societal risk into account, but integrates the consideration of different types of buildings (buildings for a lot of people, for susceptible people and/or with restricted autonomy) in the matrix for the decision making.

Based on these conclusions this benchmark study shows that the risk assessment methods used in France, the United Kingdom, the Netherlands and the Walloon Region are very different. Not only the methods and the guide values differ, but also the selection of scenarios and effect calculations with their end values vary. It is surprising that the calculated safety distances are of equal dimensions. In order to understand the differences in detail and to improve the foundations and the value of the risk assessment methodologies, further international sharing of insights and methods is desirable.

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Annex 1. Site description LPG case

INERIS, description of Sep 25, 2007.

Site description of the LPG depot

Version: September 25, 2007, Ineris

1-Introduction
This note contains the description of an LPG depot that may be retained to perform a comparison of the societal risk calculation by using HSE, RIVM and INERIS approach.

2-Installation
We propose to perform the risk assessment on a LPG storage depot whose properties are given below.

2.1 - General description

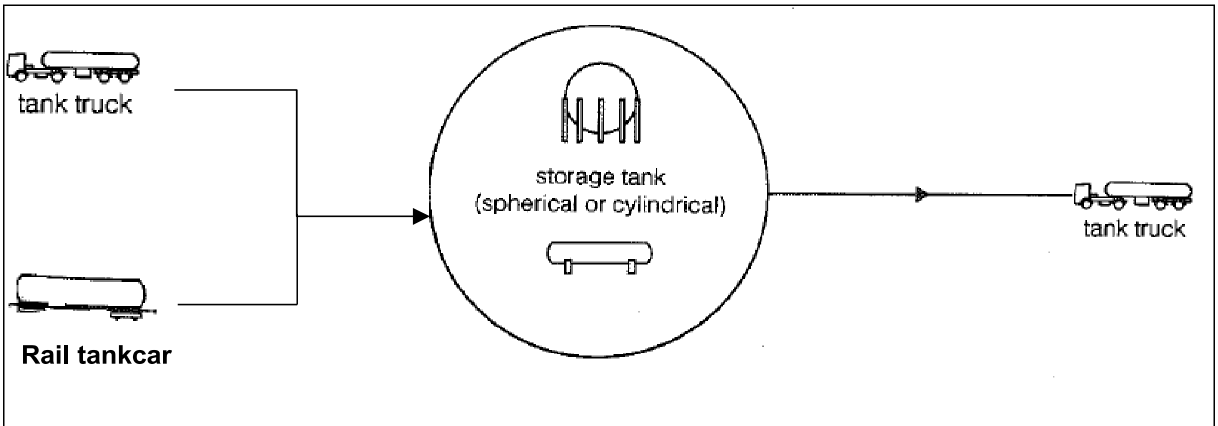


Figure A1-1 LPG storage depot

The LPG depot that is studied is made of :

- 2 cylindrical vessels in mounds (for propane) - Capacity : 2500 m^3 per vessel;
- 1 spherical vessels (for butane) - Capacity: 700 m^3;
- 3 rail tank car unloading stations (2 unloading arms for each station : 1 for the liquid line and 1 for the vapour line);
- 2 road tanker stations : 1 loading station with 1 arm for propane and 1 loading/unloading station for both propane and butane with 2 arms (1 arm for the liquid line and 1 arm for the vapour line);
- A piping system equipped with:
  - 2 pumps (capacity = 150 m^3/h for each) for the road tanker loading station (propane);
  - 1 pump (capacity = 60 m^3/h) for the road tanker loading station (butane);
  - 1 compressor (flow rate : 160 m^3/h).

  Comments (based on questions and answers)
  - We (Ineris and RIVM) suppose that all the installation have the same origin.
  - For the modeling we will use default weather data in conformity to the French regulation (Ineris and RIVM).

2.2 Description of the storage vessels

- **2 cylindrical vessels (propane) - Capacity: 2500 m^3 per vessel**

The vessels are placed on a bed of sand with a soil cover of 1 meter. Checks are regularly made for subsidence, which may result in undesirable material stress.

Diameter of each vessel: 7.2 m.
Length of each vessel: 64 m.
Maximum filling rate: 85% - Minimum filling rate : 7%.

Temperature of the product: 20 °C.
Relative pressure: **7.4 bar**.

Comments (based on questions and answers)
Use of saturated liquid at 20 °C.

For each vessel:

- ***1 Outlet line*** equipped with:
  - one internal safety shut off valve (hydraulic system - connected to the security system);
  - one safety valve (ESDV-electric system– close in less than 10s - connected to the security system).
  - Note : 1 gas detection inside the tunnel connected to the security system.

- ***1 Inlet line*** equipped with:
  - one safety shut off valve (hydraulic system - connected to the security system);
  - one safety valve (ESDV – electric system).
  - Note : inlet line and liquid return line are connected.

- ***1 Liquid return line*** equipped with:
  - one safety shut off valve (in common with the inlet line);
  - one safety valve (ESDV – electric system).

- ***1 Vapour return line*** equipped with:
  - one safety shut off valve (hydraulic);
  - one safety valve (ESDV – pneumatic system).

- ***1 Purging line*** equipped with 1 line 2” (DN50) with 1 hand-operated valve and 1 motorized safety valve then 1 purging capacity then 1 line 1”(DN25) equipped with 1 deadman valve.

- ***1 flowmeter*** to control the flow inside the outlet line (after the motorized valve) – (connected to the security system).

- ***1 internal pressure meter*** (on the vapour line): 1 manometer;
- ***1 temperature meter (on the liquid line)***: 2 transmitters in redundancy (information transmitted to control issue);
- ***2 level gauging systems*** (independent and same technology) with four level instructions (information transmitted to the control station):
  - level (5%) : pump stop;
  - level (85%) : alarm inside the area and the technical local;
  - level (90%) : alarm inside the area and the technical local - compressor stop – vessel isolation;

  - level (93%) : alarm inside the area and the technical local - compressor stop – vessel isolation – close of motorized valves and safety shut off valves;
- ***2 pressure relief valves*** (diameter : 6” (DN150) - pressure setting 15.5 bars – max flow rate 160m^3/h) – relief at 2 meters high.

- **1 spherical vessel (butane) – *Capacity*: 700 m^3**.

Maximum filling rate: 55%.
The spherical vessel is located in a tank bassin associated with another bassin that may contain 20% of the capacity of the vessel.

Comments (based on questions and answers)
- Butane is considered as saturated liquid.
- The spherical vessel is not mounded.
- 20% of the capacity of the vessel may be contained in the second bassin.
- Dimension of the basin: 8 by 8 meters.

Equipments of the spherical vessel:

- ***1 Outlet line*** equipped with one internal safety shut off valve (hydraulic – connected to the security system) and one safety valve (ESDV – pneumatic system - connected to the security system).

- ***Inlet line*** equipped with one internal safety shut off valve (hydraulic) (connected to the security system) and one safety valve (ESDV – pneumatic system - connected to the security system).

- ***Liquid return line*** equipped with one safety shut off valve and one hand-operated valve.

- ***Vapour return line*** equipped with a motorized valve (electric).

- ***Purging line***: line 2” (DN50) with 1 internal safety shut off valve (hydraulic) 1 hand-operated valve– 1 purging capacity (4”) –1 deadman valve.

- ***1 internal pressure meter*** (on the vapour line) –(information transmitted and connected to the security system);
- ***1 temperature meter (on the liquid line)*** – (information transmitted and connected to the security system);
- ***1 level gauging system with four level instructions*** – (information transmitted and connected to the security system):
  - level (5%): pump stop;
  - level (55%): alarm inside the area and the technical local;
  - level (60%): alarm inside the area and the technical local – compressor stop – vessel isolation;
  - level (93%): alarm inside the area and the technical local – compressor and pump stop – vessel isolation – close of motorized valves and safety shut off valves;
- ***2 pressure relief valves*** (pressure setting 9.7 bars) – relief at 2 meters high.

Comments (based on questions and answers)
- Diameter : 6” (DN150).
- The direction of the release is vertical.

2.3 Description of the pumps

Pumps:
Propane pump – 2 pumps – Capacity (max): 150 m^3/h.
Heads to 22 bar.
Butane pump – 1 pump – Capacity (max): 60 m^3/h.

Comments (based on questions and answers)
- Centrifugal pumps and compressor.

2.4 Description of the compressor

***Compressor**:*
1 compressor.
Flow rate (max): 160 m^3/h.

2.5 Description of the loading-unloading stations

Road tanker unloading station (one unloading station / one loading station):

- Transshipment from a tank truck:
  - There are 150 road tanker deliveries per year. (Capacity : 47 m^3).
  - The duration of a delivery is assumed to be 1 hour of actual flow (1 hour = presence of the tanker : 45 minutes for the transshipment operation and 15 minutes for decompression phase).
  - 90% of the deliveries are PROPANE. See table hereafter.
- Transhipment to a tank truck:
  - There are 2800 road tanker transhipment a year.
  - The duration of a delivery is assumed to be 20 minutes.

(Max 2 road tanker at the same time).

- Road tanker characteristics:
  - filling rate: 100%.
- Arm:
  - liquid pipe: 3″×3″;
  - vapour pipe: 3″×2″.
- Isolating system:
  - 1 safety shut off valve at the bottom of the road tanker;
  - 1 fracture point (Flip Flap);
  - 1 safety valve (pneumatic system) for each station.
- Unloading pressure: ΔP = 1 bar.

<u>**Rail tankcar unloading station (3 unloading stations)**</u> :
- Transhipment from a rail tankcar:
  - 900 transhipments per year (**only propane**);
  - The duration of a delivery is assumed to be 2 hours.
- Rail tanker characteristics:
  - Capacity: 119m^3 (filling rate: 100%).
- Arm:
  - Liquid pipe : 3″×3″;
  - Vapour pipe : 3″×2″.
- Isolating system:
  - 1 safety shut off valve at the bottom of the rail tank car;
  - hand operated valves on the tank car;
  - 1 pneumatical rigging screw;

    - 1 fracture point (Flip Flap);
    - 1 safety valve (pneumatic system).
- Unloading pressure : ΔP = 1 bar.

Synthesis:

	Product	**Capacity**	**Flow rate (m^3/h)**	**Filling rate**	**Number of un(loading) per year**	**Duration (total time staying)**
Loading the road tanker						
	Propane	21 m^3	60	85%	2750	In average 20 minutes
		47 m^3	60	85%	15	
	Butane	21 m^3	60	85%	35	
Unloading the road tanker	Propane	47 m^3	60	85%	135	1 hour
	Butane	47 m^3	60	85%	15	1 hour
Unloading rail tankcar	Propane	119 m^3	100	85%	900	2 hours

The flow rate for the road tanker is also 60 m^3/hr.

The flow rate for the tankcar unloading is 100 m^3/hr.

2.6 Other safety devices

- Flammable and gas detection in bunds containing vessels, pumps or tanks connected to the security system.
- Emergency stop-push button connected to the security system.

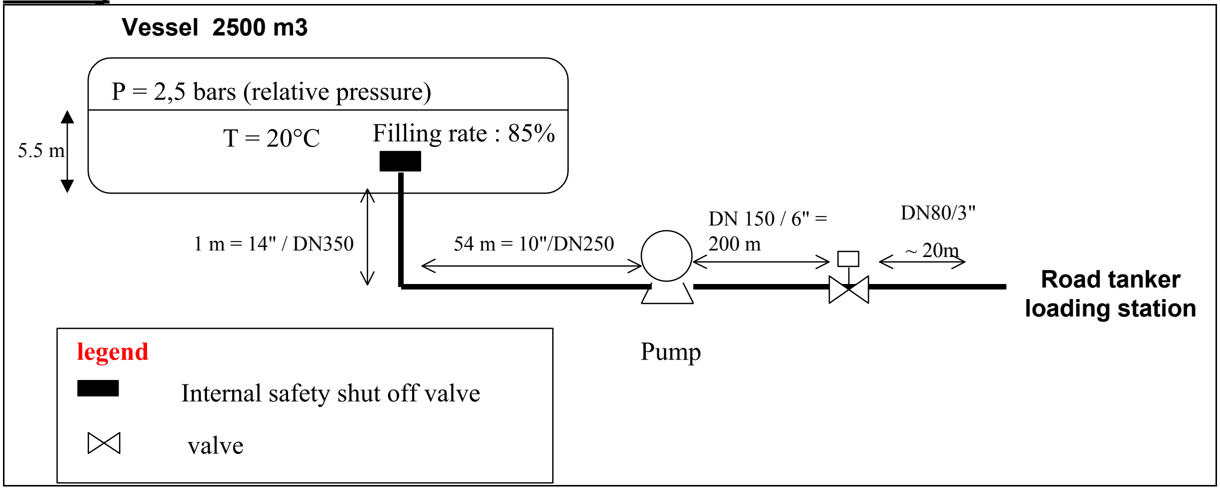
If gas or flamme are detected all remote controlled valves are closed automatically and the process will be stopped.
By activating the emergency stop all remote controlled valves are closed automatically and the process will be stopped.

- **Firewater management:**
  3 pumps – capacity = 500m^3/h.

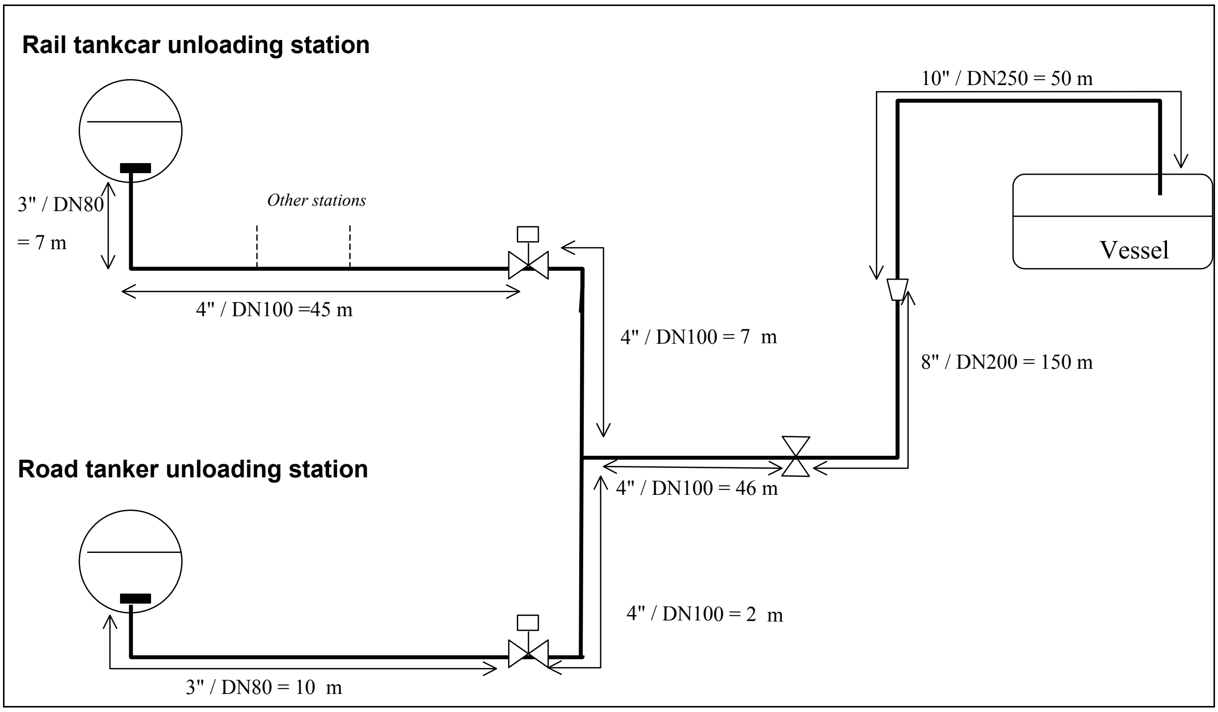
Piping system:

Piping	Diameter
RST-Compressor	6" (DN150), 4"(DN100)
Compressor – unloading station (rail tank car)	2" (DN50), 3"(DN80)
Compressor – unloading station (road tanker)	2" DN50), 3"(DN80), 4"(DN100), 3"(DN80)
RST-Pump	14" (DN350), 10" (DN250)
Pump – loading station (road tanker)	6" (DN150), 3" (DN80)
Unloading station (rail tankcar) – RST (liquid)	3" (DN80), 4" (DN100), 8" (DN200), 10" (DN250)
Unloading station (road tanker) – RST (liquid)	3" (DN80), 4" (DN100), 8" (DN200), 10" (DN250)
Unloading station (rail tank car) – spherical vessel (liquid)	4" (DN100)
Unloading station (road tanker) – spherical vessel (liquid)	4" (DN100)
Spherical vessel – Compressor	3"(DN80), 2" (DN50)
Spherical vessel - Pump	4" (DN100), 6" (DN150)

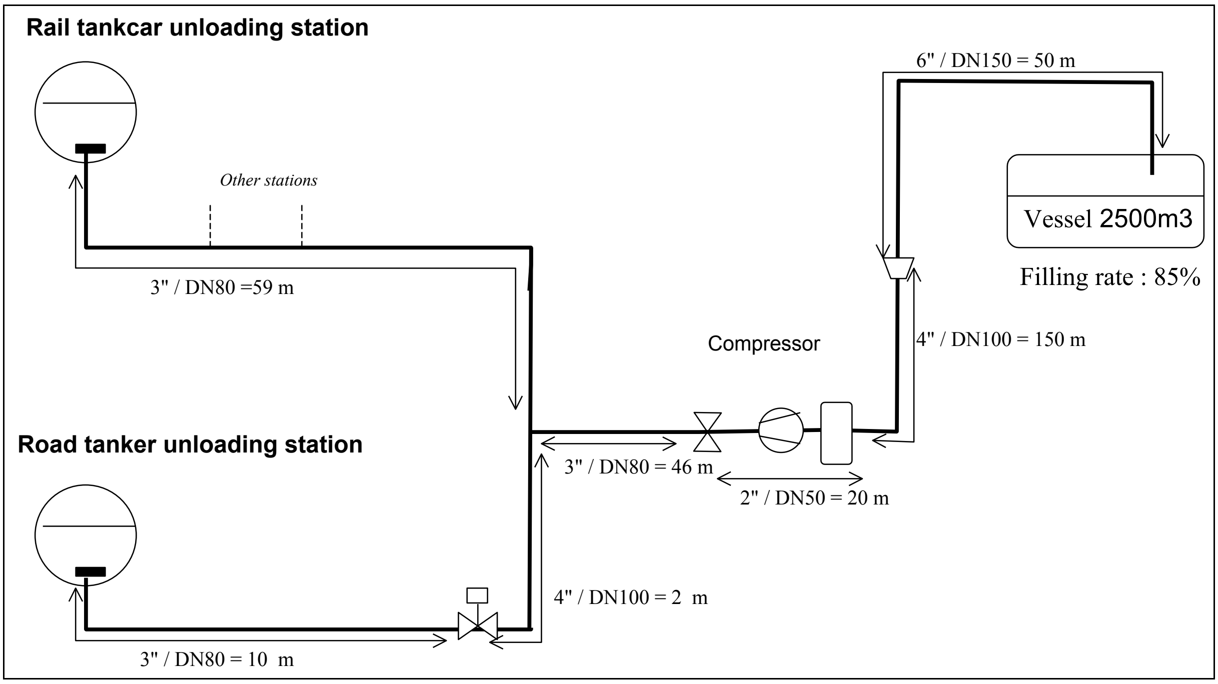
Loading:



Unloading (1): liquid line



Unloading (2): vapour line



Annex 2. INERIS report LPG comparison study

INERIS, report of September 9, 2009

RAPPORT D’ÉTUDE 07/12/2009
DRA-09-102989-11125A

INERIS part - Benchmark study of a LPG plant

ANNEX 2 – INERIS part - Benchmark study of a LPG plant

Verneuil-en-Halatte (60)

Client: Ministère de l'Écologie, de l'Énergie, du Développement durable et de la Mer (MEEDM)

Liste des personnes ayant participé à l'étude : Cécile DEUST, Régis FARRET, Clément LENOBLE.

PREAMBULE

Le présent rapport a été établi sur la base des informations fournies à l'INERIS, des données (scientifiques ou techniques) disponibles et objectives et de la réglementation en vigueur.

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Visa				

table des MATIÈRES

1. Glossary

ALARP	As Low As Reasonably Practicable
BLEVE	Boiling Liquid Expanding Vapour Explosion
FPMs	Faculté Polytechnique de Mons (Belgium)
HSE	Health and Safety Executive (Great-Britain)
INERIS	Institut National de l’Environnement Industriel et des Risques (France)
LPG	Liquefied petroleum gas
MMR	Mesure de Maîtrise des Risques
PPRT	Plan de Prévention des Risques Technologiques
RIVM	Rijksinstituut voor Volksgezondheid en Milieu

2. Introduction

In France, in the Netherlands, in Great-Britain and in Belgium, risk calculations are carried out to determine hazardous areas around SEVESO II facilities. The outcomes of the risk calculations are subsequently used for permitting and land use planning. The regulatory context behind the risk calculations and the methodologies used for calculation are different. A benchmark exercise was carried out to compare the French, the Dutch, the British and the Belgium approaches. This benchmark comprises a fictitious storage facility for LPG (upper tier SEVESO II) in a fictitious surroundings.

INERIS has performed the risk calculation in the French regulation context. This study has been carried out in the framework of the EAT-DRA 74 program, Operation 1 "Négociation territoriale des risques" for the French ministry of environment (Ministère de l'écologie, de l'énergie du développement durable et de la mer (MEEDDM)).

This report includes a description of the fictive facility retained in the framework of this study, a brief description of the French regulatory context and the methodology used by INERIS for performing risk assessments, and a presentation of the results.

This report is the 2nd annex of the general report of the benchmark written by the HSE, FPMs, RIVM and INERIS.

3. General description of the fictive LPG depot

3.1 General description

The figure presents a simplified schema of the studied facility.

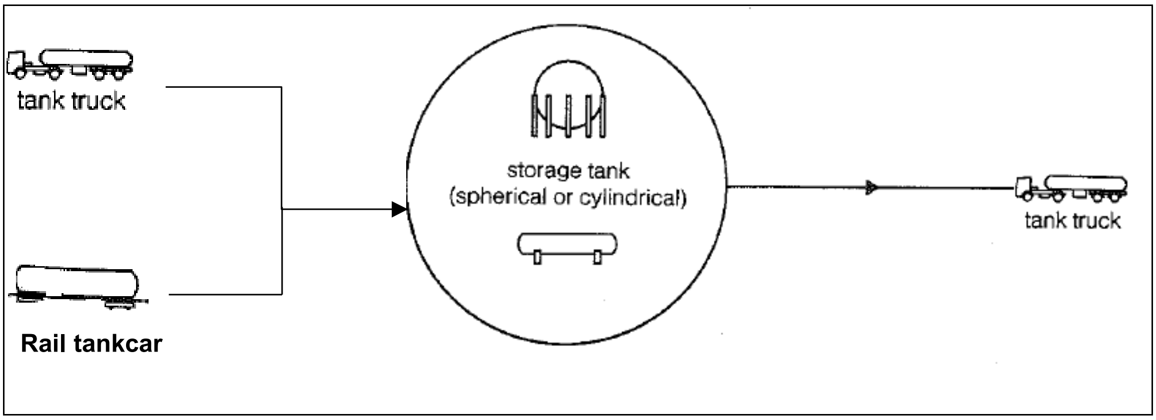


Figure A2-1 Simplified schema of the LPG fictive depot

The studied LPG depot is composed of:

- 2 cylindrical vessels in mounds (for propane) - Capacity : 2500 m^3 per vessel;
- 1 spherical vessel (for butane) - Capacity : 700 m^3;
- 3 rail tank-car unloading stations;
- 2 road tanker stations;
- the piping system is composed of the following equipments:
  - 2 pumps for the road tanker loading station (propane);
  - 1 pump for the road tanker loading station (butane);
  - 1 compressor.

3.2 Storage vessels

3.2.1 Two cylindrical vessels (propane):

Each vessel has a capacity of 2500 m^3. The vessels are placed on a bed of sand with a soil cover of 1 meter. Checks are regularly made for subsidence, which may result in undesirable material stress.

General data:

- **diameter** of each vessel: 7,2 m;
- **length** of each vessel: 64 m;
- maximum **filling rate** : 85% - Minimum filling rate: 7%;
- **temperature** of the product : 20°C;
- relative **pressure**: 7,4 bar.

Equipments:

- **Outlet line** equipped with:
  - one internal safety shut off valve (hydraulic system - connected to the security system);
  - one safety valve (ESDV- electric system – close in less than 10s - connected to the security system);
  - one gas detection inside the tunnel connected to the security system.
- **Inlet line** equipped with :
  - one safety shut off valve (hydraulic system - connected to the security system);
  - one safety valve (ESDV – electric system);
  - inlet line and liquid return line are connected.
- **Liquid return line** equipped with :
  - one safety shut off valve (in common with the inlet line);
  - one safety valve (ESDV – electric system).
- **Vapor return line** : equipped with :
  - one safety shut off valve (hydraulic);
  - one safety valve (ESDV – pneumatic system).
- **Purging line** equipped with one line 2" (DN50) with one hand-operated valve and one motorized safety valve then one purging capacity then one line 1" (DN25) equipped with a "dead man" valve.
- One **flow meter** to control the flow inside the outlet line (after the motorized valve) – (connected to the security system).
- One internal **pressure meter** (on the vapor line) : one manometer.
- One **temperature meter** (on the liquid line): two transmitters in redundancy (information transmitted to control issue).
- Two **level gauging** systems (independent and same technology) with four level instructions (information transmitted to the control station) :
  - Level (5%) : pump stop;
  - Level (85%) : alarm inside the area and the technical local;
  - Level (90%) : alarm inside the area and the technical local - compressor stop – vessel isolation;
  - Level (93%): alarm inside the area and the technical local - compressor stop – vessel isolation – close of motorized valves and safety shut off valves.
- Two **pressure relief valves** (diameter: 6" (DN150) - pressure setting 15,5 bars – max flow rate 160m^3/h) – relief at 2 meters high.

3.2.2 Spherical vessel (butane):

The vessel has a capacity of 700 m^3. The spherical vessel is located in a tank basin associated with another basin that may contain 20% of the capacity of the vessel. The maximum filling rate is 55%.

Equipments:

- **Outlet line** equipped with one internal safety shut off valve (hydraulic – connected to the security system) and one safety valve (ESDV – pneumatic system - connected to the security system).

- **Inlet line** equipped with one internal safety shut off valve (hydraulic) (connected to the security system) and one safety valve (ESDV – pneumatic system - connected to the security system).
- **Liquid return line** equipped with one safety shut off valve and one hand-operated valve.
- **Vapour return line** equipped with a motorized valve (electric).
- **Purging line** : line 2” (DN50) with one internal safety shut off valve (hydraulic), one hand-operated valve– one purging capacity (4”) –one dead man valve.
- One internal **pressure meter** (on the vapor line) –(information transmitted & connected to the security system).
- One **temperature meter** (on the liquid line) – (information transmitted & connected to the security system).
- One **level gauging** system with four level instructions – (information transmitted & connected to the security system):
    - level (5%) : pump stop;
    - level (55%) : alarm inside the area and the technical local;
    - level (60%) : alarm inside the area and the technical local – compressor stop – vessel isolation;
    - level (93%): alarm inside the area and the technical local – compressor and pump stop – vessel isolation – close of motorized valves and safety shut off valves.
- Two **pressure relief valves** (pressure setting 9,7 bars) – relief at 2 meters high.

3.2.3 Pumps and compressor

- Propane: two **pumps**, flow rate (max) 150 m^3/h, heads to 22 bar.
- Butane: one **pump**, flow rate (max) 60m^3/h.
- One **compressor**, flow rate (max) 160 m^3/h.

3.2.4 Loading and unloading activities

Road tanker unloading station:

- **One unloading station and one loading station** (two road tankers maximum at the same time).
- **Transshipments from a tank truck:**
    - there are 150 road tanker deliveries per year;
    - the duration of a delivery is assumed to be 1 hour of actual flow (45 minutes for the transshipment operation and 15 minutes for decompression phase);
    - 90% of the deliveries are propane.
- **Transshipments to a tank truck:**
    - there are 2800 road tanker transshipments a year;
    - the duration of a delivery is assumed to be 20 minutes.
- **Road tanker** characteristics:
    - tank capacity: 47 m^3;
    - filling rate: 100%.
- **Arms:**
    - liquid pipe : 3”×3”;
    - vapour pipe: 3”×2”.

- **Isolating system:**
  - one safety shut off valve at the bottom of the road tanker;
  - one fracture point (Flip Flap);
  - one safety valve (pneumatic system) for each station.
- Unloading **pressure**: ∆P = 1 bar.

Rail tank car unloading station:

- **Three unloading stations** (propane).
- **Transshipment from a rail tank car**:
  - there are 900 transshipments per year;
  - the duration of a delivery is assumed to be 2 hours.
- **Rail tanker** characteristics:
  - tank capacity : 119m^3;
  - filling rate: 100%.
- **Arm:**
  - liquid pipe : 3″×3″;
  - vapour pipe: 3″×2″.
- **Isolating system:**
  - one safety shut off valve at the bottom of the rail tank car;
  - hand operated valves on the tank car;
  - one pneumatic rigging screw;
  - one fracture point (Flip Flap);
  - one safety valve (pneumatic system).
- Unloading **pressure**: ∆P = 1 bar.

3.2.5 Piping system

The next table presents the main data related to piping system.

Table A2-1 Data related to piping system

Pipes	Diameter
Mounded vessel-Compressor	6″ (DN150), 4″(DN100)
Compressor – unloading station (rail tank car)	2″ (DN50), 3″(DN80)
Compressor – unloading station (road tanker)	2″ (DN50), 3″(DN80), 4″(DN100), 3″(DN80)
Mounded vessel-Pump	14″ (DN350), 10″ (DN250)
Pump – loading station (road tanker)	6″ (DN150), 3″ (DN80)
Unloading station (rail tank car) – mounded vessel (liquid)	3″ (DN80), 4″ (DN100), 8″ (DN200), 10″ (DN250)
Unloading station (road tanker) – mounded vessel (liquid)	3″ (DN80), 4″ (DN100), 8″ (DN200), 10″ (DN250)
Unloading station (rail tank car) – spherical vessel (liquid)	4″ (DN100)
Unloading station (road tanker) – spherical vessel (liquid)	4″ (DN100)
Spherical vessel – Compressor	3″(DN80), 2″ (DN50)
Spherical vessel – Pump	4″ (DN100), 6″ (DN150)

3.2.6 *Other safety devices*

- Flammable and gas detection in bunds containing vessels, pumps or tanks connected to the security system.
- Emergency stop-push button connected to the security system.

When gas or flames are detected, all remote controlled valves are closed automatically and the process will be stopped.

By activating the emergency stop, all remote controlled valves are closed automatically and the process will be stopped.

- Firewater management : three pumps – capacity = 500m^3/h

3.2.7 *Population in the vicinity of the facility*

A population has been defined in the vicinity of the fictive depot in an area of 30 km x 30 km. This population has been distributed into a grid of cells (1 km x 1 km). Each cell has a different density of population. Within a cell, there is a uniform distribution of population.

The Figure A2-2 presents the population data used in the context of this study.

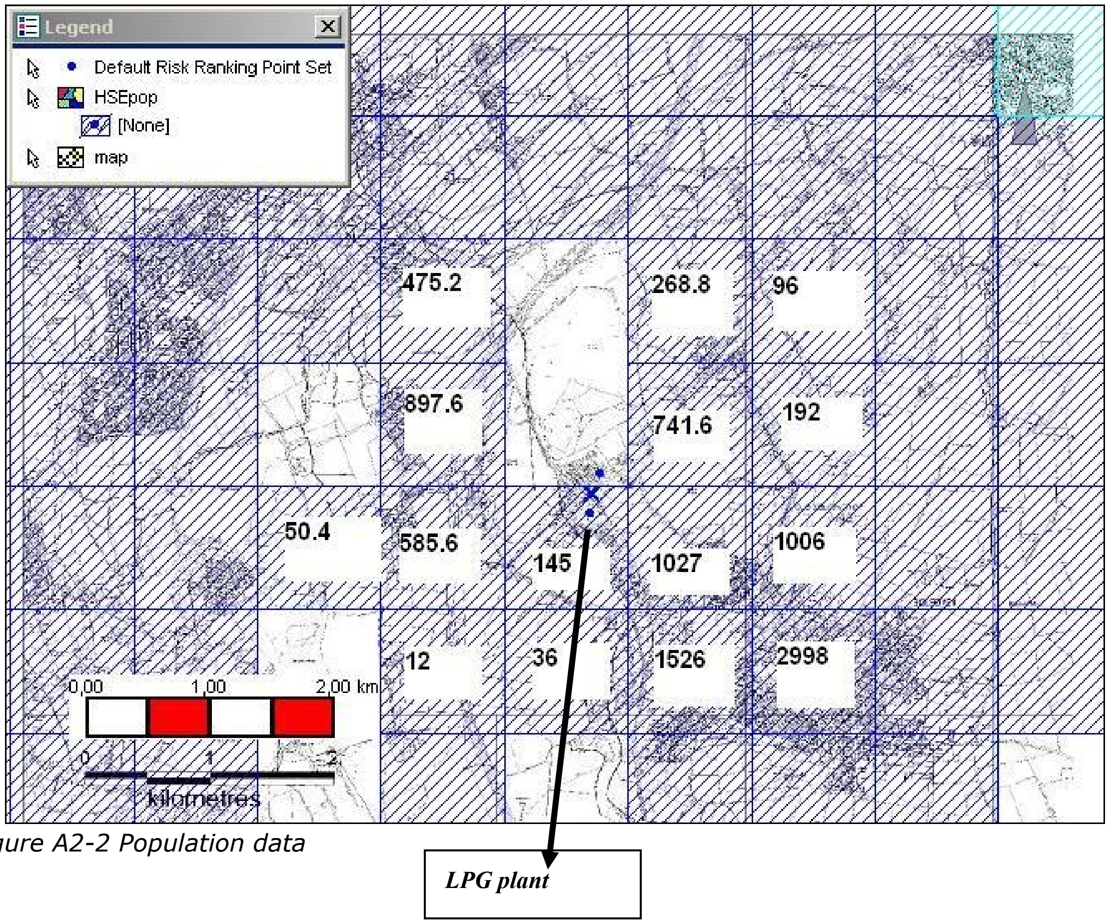


Figure A2-2 Population data

4. French regulatory context of the safety report

4.1 Definitions

The following terms are used in the French regulatory context.

Dangerous phenomenon: Energy or substance discharge which produces effects and may produce damages to vulnerable target (living beings or objects).

Effects of a dangerous phenomenon: characteristics of physical, chemical… phenomena linked to dangerous phenomena: thermal radiation, toxic concentration, overpressure and missiles.

Intensity of a dangerous phenomenon: Physical measure of dangerous phenomena effects (thermal, toxic, overpressure and missiles).

Severity: Combination of dangerous phenomena effect intensity and the vulnerability of people potentially exposed at a given point.

Alea: Combination of occurrence probability and effect intensity of dangerous phenomena at a given point.

Kinetic: This term refers to the time scale of an accident and the time needed for evacuating local populations. Fast kinetic events involve dangerous effects that may occur rapidly after the beginning of the central event (an example of central event is a pipe leak of hazardous substance). Examples of fast kinetic events are flash fire, pool fire, tank explosion and vapour cloud explosion. Slow kinetic events are events that only occur after some delay. This delay would allow local population to evacuate. Some examples of low kinetic dangerous phenomena are boil-over and fireball after pressurization (due to heat impingements).

Accident: Undesirable event such as a discharge of toxic substance, a fire or an explosion which cause consequences and damages on human being, goods or environment. The accident is produced by a dangerous phenomenon, when vulnerable targets are exposed to its effects.

Safety report: Study performed by the operator of a SEVESO establishment and presented to the administration. This study describes the risks the establishment generates for vulnerable targets outside the establishment (such as local population, goods and environment; workers of the establishment are not taken into account in this study). This study is the result of a risk analysis which takes into account the occurrence probability, the kinetic and the severity of potential accidents.

PPRT: Technologic Risk Prevention Plan (Plan de prévention des risques technologiques). This plan is designed and performed by the State on the basis of the safety report. It aims to limit the consequences of a potential accident through land-use planning and modification of the present land-use. This plan is set on the basis of alea and vulnerability maps through a governance process.

Assessment of the risk control: this assessment is performed by the inspection during the analysis of the safety report. This process aims to check the owner of a SEVESO establishment implements all the risk reduction measures available at an acceptable cost in order to reduce the probability or the severity of potential major accidents. This process may be performed using a risk matrix (probability-severity matrix).

4.2 Introduction

In France, two decision support tools are used by the authorities in order to evaluate the risk generated by upper-tiers SEVESO facilities:

- The risk matrix for the permit to operate delivering process. This matrix is comparable to societal risk.

- The "Plan de Prévention des Risques Technologiques" (PPRT – Technological risk prevention reduction plan). This process use « aléas » maps which can be compared with individual risk.

These two decision support tools use the following data of the safety report:

- The kinetic of dangerous phenomena: the kinetic of dangerous phenomena can be fast or slow.
- The occurrence probability of dangerous phenomena/accidents:

  They are expressed with regard to a national probability scale. The Table A2-2 presents this scale:

  Table A2-2 French national probability scale (see [3])

Probability class	E	D	C	B	A
Range of probability	0 to 10^{-5}	10^{-5} to 10^{-4}	10^{-4} to 10^{-3}	10^{-3} to 10^{-2}	10^{-2} to 1

- The effect distances of dangerous phenomena:

  They are expressed with regard to end-point values. The Tabel A2-3 presents the end-point values used in France:

  Table A2-3 End-point values used in France (see [3])

Effects	Level of effects			
	Significant lethal effect threshold	**Lethal effect threshold**	**Irreversible effect threshold**	**Indirect**
Thermal	8 kW/m^2 or (1800 kW/m^2)$^{4/3}$s	5 kW/m^2 or (1000 kW/m^2)$^{4/3}$s	3kW/m^2 or (600 kW/m^2)$^{4/3}$s	/
Overpressure	200 mbar	140 mbar	50 mbar	20 mbar

The risk matrix and the PPRT are briefly presented in the following paragraphs.

More detailed information on the French regulatory context is available in [15].

4.3 Risk matrix

The risk matrix is a tool that analyses each potential major accident with regard to its probability of occurrence and its severity level (see the definition of assessment of risk control).

The severity level is defined by the number of persons potentially exposed to a given dangerous phenomenon. The severity is characterized with regard to a national regulatory scale. The Table presents this scale:

Table A2-4 French severity scale (see [3])

Severity	Significant lethal effect	Lethal effect	Irreversible effect
Disastrous	>10	>100	>1000
Catastrophic	1 to 10	10 to 100	100 to 1000
Significant	1	1 to 10	10 to 100
Serious	0	1	1 to 10
Moderate	0	0	< 1

The next Table presents the French risk matrix:

Table A2-5 French risk matrix (see [4])

Probability	E	D	C	B	A

Severity					
Disastrous	ALARP class 2	Unacceptable	Unacceptable	Unacceptable	Unacceptable
Catastrophic	ALARP class 2	ALARP class 2	Unacceptable	Unacceptable	Unacceptable
Significant	ALARP	ALARP	ALARP class 2	Unacceptable	Unacceptable
Serious	Acceptable	Acceptable	ALARP	ALARP class 2	Unacceptable
Moderate	Acceptable	Acceptable	Acceptable	Acceptable	ALARP

This risk matrix is composed by three areas:

- an acceptable area (in white);
- an unacceptable area (in red);
- an "ALARP" (As Low As Reasonably Practicable) area (in yellow) where continuous improvement of the safety is asked to operators. There is one specific ALARP case area:
    - ALARP class 2: The total number of accident scenarios in the ALARP 2 boxes of the diagram must be 5 or lower. If there are more than 5 accident scenarios, additional technical barriers must be installed such that the amount of ALARP class 2 accidents reduces to five (or less). More than five ALARP class 2 accidents are acceptable if and only if they all have at least one barrier and if each of these accidents has a probability far smaller than 10-5 per year (official terminology: if all scenarios have at least one barrier, and if this barrier was not considered, the remaining frequency would still be E). For all other cases, the situation is considered as unacceptable.

If a facility generates a risk that is considered as unacceptable, the operator has the responsibility, on its own funds, to improve the safety in the establishment and to install additional safety measures. The safety must be improved until the situation becomes acceptable or ALARP.

4.4 Technological risk prevention plan (PPRT)

The Technological Risk Prevention Plan (PPRT) enables the authorities to:

- modify the actual land use in order to reduce risk;
- define a land use plan for the future in the vicinity of the facility.

In order to reach these objectives, the authorities first define seven different areas around the facility, each area relating to a different regime of risk (alea level), which is determined by the intensity of the effects and the probability of occurrence (see Table A2-6).

Table A2-6 "Alea" levels definition (see [8])

Maximum intensity of the toxic, thermal or overpressure effects on human at a given point	Significant lethal			Lethal			Irreversible			Indirect
Cumulative probability distribution of dangerous phenomena at a given point	>D	5E to D	<5E	>D	5E to D	<5E	>D	5E to D	<5E	All
"Aléa levels"	VH+	VH	H+		H	M+		M	Low	

As soon as these areas are laid on the map, together with the surrounding vulnerable houses, buildings, and infrastructures, a "strategy" for the land use and the reduction of the risk has to be planned. This strategy is designed through a governance protocol involving the inhabitants, the industrialist, the local communities, local associations, local employees, the State, etc.

Guidance is given by the French Ministry for piloting the definition of the strategy. A part of this guidance is presented in Table A2-7.

Table A2-7 Guidance for the definition of real estate measures

<table>
<tr><th>“Aléa levels”</th><th>VH+</th><th>VH</th><th>H+</th><th>H</th><th>M+</th><th>M</th><th>Low</th></tr>
<tr><td>Expropriation</td><td>Automatic for housing buildings.
To be defined for other activities</td><td>To be defined</td><td colspan="5">No</td></tr>
<tr><td>Relinquishment</td><td>Automatic</td><td colspan="2">Automatic for housing buildings.
To be defined for other activities.</td><td>To be defined</td><td colspan="3">No</td></tr>
</table>

The PPRT strategy aims to modify an actual land use in the vicinity of a dangerous facility, and also aims to define a land use plan for new buildings and infrastructures. The French Ministry gives also guidance for land use planning issues. A part of this guidance is reproduced in Table A2-8.

Table A2-8 Guidance for land-use planning in the vicinity of top tiers SEVESO facilities

<table>
<tr><th>“Aléa levels”</th><th>VH+</th><th>VH</th><th>H+</th><th>H</th><th>M+</th><th>M</th><th>Low</th></tr>
<tr><td>Thermal and toxic effects</td><td colspan="2" rowspan="2">Ban on new construction</td><td colspan="2" rowspan="2">Ban on new construction but possibility to extend existing industrial buildings and infrastructure if they are protected</td><td>New construction possible depending on limitations on use or protection measures</td><td>New construction possible depending on minor limitation on use. Compulsory protection measures for public buildings and industries. No public building hard to evacuate</td><td></td></tr>
<tr><td>Overpressure effects</td><td colspan="2">Protection measures on new buildings</td><td>New construction possible depending on minor limitation on use. Compulsory protection measures for public buildings and industries. No public building hard to evacuate</td></tr>
</table>

5. Methodology used by INERIS in the framework of this study

In France there is no compulsory methodology for risk assessment. The operators are free to choose the methodology to use in their safety report (for identification of scenarios, probabilistic quantification and effect distance calculations). However, these methodologies have to be relevant.
In this paragraph the methodologies and tools used by INERIS in order to perform the risk assessment is presented. In the followings the issues which are presented are:

- the scenario identification;
- the scenario frequencies;
- the effect distance calculations.

5.1 Scenario identification

In the methodology used by INERIS, the identification of accident scenarios (from root causes to the accident) which could occur on the studied establishment is usually realised through a risk analysis (according to a methodology such as HAZOP, FMECA, preliminary risk analysis, etc).
In this aim, a working group is gathered. For example, it could consist of the plant safety manager, several operators and risk experts. This working group will identify the following elements of the accident scenario:

- the central events to be considered;
- the root causes lying underneath the central events. Typical root causes are seal failure, operator errors, falling objects, etc.;
- the consequences events of the central events;
- the barriers which may prevent the occurrence of the accident. Prevention and protection barriers are considered if they meet the following requirements:
  - independence regarding the occurrence of the event they prevent and regarding to the devices used to produce;
  - effectiveness;
  - response time adapted to the kinetic of the accident they prevent;
  - maintainable;
  - testable.

Once the identification process is realized, the scenario frequencies can be calculated.
For more detailed information on the methodologies used here, see [15].

5.2 Scenario frequencies

In the methodology used in this study by INERIS, the frequency of central events is derived from root causes frequencies and prevention barriers reliability.

Each root cause frequency is derived by a working group which may gather the risk manager of the facility, operators, maintenance teams, experts…. They are expressed using frequency classes.
The confidence level of each barrier is also assessed as a probability (reduction) range.
Root causes that lead to a common intermediate event, such as seal leak and flange leak, are combined using AND and OR operators:

- If any of the root causes can cause the intermediate event, an OR operator is used. In that case, the frequency class of the intermediate event is equal to the minimum frequency class of the root causes.

- If multiple root causes are required for the occurrence of the intermediate event, an AND operator is used. In this case, the frequency class of the intermediate event is equal to the sum of the frequency class of the required root causes.
- If a prevention barrier exists, the confidence level of the barrier is added to the frequency class of the cause, which gives the frequency class of the intermediate event.

Intermediate events are further combined into release events, such as leak from the tank or leak from accessories of the tank. Release events are then further combined into central events, such as a pool in the bund or a pool on the roof of a tank.

According to this methodology, the accident scenario to be considered, the assessment of the frequency of roots causes and the probability of failure of prevention barriers is specific for each establishment.

5.3 Effect distance calculations

The models used by INERIS in this study are presented in the Table A2-9

Table A2-9 Models used by INERIS in this study

Dangerous phenomena	Models used	Theory used
Pool evaporation	PHAST 6.5 (DNV)	TNO and Mackay and Matsugu correlation.
Vapour Cloud Explosion (VCE)	Effex (INERIS)	Quantification of pressure increasing in the building + Explosion Energy quantification + Multi Energy abacus.
Vapour Cloud Explosion (VCE)	Projex (INERIS)	Explosion Energy from Brode formula + Multi Energy abacus.
UVCE (Unconfined Vapour Cloud Explosion)	Multi Energy (TNO)	Strength assessment of explosion through a severity class choice.
Boiling Liquid Expansion Vapour Explosion (BLEVE)	INERIS model	**Thermal effects:** Based on T.R.C. Shield model. **Overpressure effects:** Explosion Energy from Brode formula + Multi Energy abacus.
Jet fire	Phast 6.5 (DNV)	Different empirical correlations.

6. Results

The following issues are presented in this chapter:

- results of probabilistic quantifications and effect distance calculations of retained dangerous phenomena;
- the application of the MMR matrix for the fictive case of this LPG depot and the surrounding population;
- the "alea maps" for the fictive case of this LPG depot (drawn using the INERIS tool SIGALEA).

6.1 Probabilistic quantification and effect distances calculations

Thirty eight dangerous phenomena have been retained for the study of the fictive LPG depot. Among these dangerous phenomena, three have been excluded of the analysis considering the following issue:

- Breaches and leaks on pipe and loading/unloading arms: the bow-tie diagrams used in the framework of this study show that these events have similar frequencies with rupture events. However, the consequences of these losses of containment are less severe. As a consequence, only the rupture events have been retained for further analysis (conservative approach);

The Table A2-10 presents the results of the analysis for the thirty five dangerous phenomena studied. For each dangerous phenomenon, the information presented is the following:

- the name;
- the occurrence probability in accordance to the national probability scale;
- the type of effect studied;
- the effect distances for each end point value used in France;
- the number of people exposed to each effect zone;
- the severity of the major accident in accordance to the national severity scale.

Table A2-10 Results of INERIS approach

Dangerous phenomenon n°	Commentaries	Occurrence probability	Effect	Sign. Let. effects	Let. effects	Irrev. effects	Sign. Let. effect	Let. effects	Irrev. effects	Severity category
				m	m	m	People exposed	People exposed	People exposed	
1	Jet fire on road tanker transshipment post : loss of containment on loading/unloading arm : full bore rupture-without isolating system	E	Thermal	155	175	195	11.0	3.5	5.1	Disastrous
2	Jet fire on road tanker transshipment post : loss of containment on loading/unloading arm : full bore rupture-with isolating system (20 s)	D	Thermal	155	175	195	11.0	3.5	4.4	Disastrous
3	VCE on road tanker transshipment post : loss of containment on loading/unloading arm : full bore rupture-without isolating system	E	Overpressure	0	0	210	0.0	0.0	22.1	Significant
4	VCE on road tanker transshipment post : loss of containment on loading/unloading arm : full bore rupture-with isolating system (20 s)	D	Overpressure	0	0	210	0.0	0.0	20.3	Significant
5	Flashfire on road tanker transshipment post : loss of containment on loading/unloading arm : full bore rupture-without isolating system	E	Thermal	170	170	190	13.9	0.0	3.0	Disastrous
6	Flashfire on road tanker transshipment post : loss of containment on loading/unloading arm : full bore rupture-with isolating system (20 s)	D	Thermal	170	170	190	13.9	0.0	3.0	Disastrous
7	BLEVE on road tanker transshipment post: loss of containment on road tanker: Instantaneous release-(Filled at 85%)	D	Thermal	145	195	240	9.7	7.8	8.3	Catastrophic
8	Burst on road tanker transshipment post : loss of containment on road tanker : continuous release-(Partly filled)	D	Overpressure	45	60	140	0.9	0.7	7.4	Significant

Dangerous phenomenon n°	Commentaries	Occurrence probability	Effect	Sign. Let. effects	Let. effects	Irrev. effects	Sign. Let. effect	Let. effects	Irrev. effects	Severity category
				m	m	m	People exposed	People exposed	People exposed	
9	Jet fire on road tanker transshipment post : loss of containment on loading/unloading arm : medium size leak (outflow is from a leak with an effective diameter of 1")-with isolating system	D	Thermal	30	40	45	0.6	0.2	0.2	Serious
10	Jet fire on rail tank car transshipment post : loss of containment on unloading arm : full bore rupture-without isolating system	E	Thermal	155	175	195	11.0	3.5	5.1	Disastrous
11	Jet fire on rail tank car transshipment post : loss of containment on unloading arm : full bore rupture-with isolating system (20 s)	D	Thermal	120	130	140	6.0	1.8	1.9	Catastrophic
12	VCE on rail tank car transshipment post : loss of containment on unloading arm : full bore rupture-without isolating system	E	Overpressure	0	0	210	0.0	0.0	20.3	Significant
13	VCE on rail tank car transshipment post : loss of containment on unloading arm : full bore rupture-with isolating system (20 s)	D	Overpressure	0	0	190	0.0	0.0	14.1	Significant
14	Flashfire on rail tank car transshipment post : loss of containment on unloading arm : full bore rupture-without isolating system	E	Thermal	170	170	190	13.9	0.0	4.0	Disastrous
15	Flashfire on rail tank car transshipment post : loss of containment on unloading arm : full bore rupture-with isolating system (20 s)	D	Thermal	140	140	155	8.8	0.0	2.2	Catastrophic
16	Burst on rail tank car transshipment post : loss of containment on unloading arm : continuous release-(partly filled)	D	Overpressure	60	80	190	1.7	1.3	13.7	Catastrophic
17	Jet fire on rail tank car transshipment post : loss of containment on unloading arm : medium size leak (outflow is from a leak with an effective diameter of 1")-	D	Thermal	30	40	45	0.6	0.1	0.1	Significant

Dangerous phenomenon n°	Commentaries	Occurrence probability	Effect	Sign. Let. effects	Let. effects	Irrev. effects	Sign. Let. effect	Let. effects	Irrev. effects	Severity category
				m	m	m	People exposed	People exposed	People exposed	
18	BLEVE on rail tank car station post: loss of containment on rail tank car: instantaneous release-(filled at 85%)	E	Thermal	220	285	355	22.1	12.3	24.9	Disastrous
23	Jet fire on piping system : loss of containment on pipe (10") : full bore rupture-without isolating system	E	Thermal	330	370	410	58.0	20.0	30.0	Disastrous
24	Jet fire on piping system : loss of containment on pipe (10") : full bore rupture-with isolating system	E	Thermal	275	295	320	45.0	7.0	8.0	Disastrous
25	UVCE on piping system : loss of containment on pipe (10") : full bore rupture-without isolating system	E	Overpressure	0	0	540	0.0	0.0	287.7	Catastrophic
26	UVCE on piping system : loss of containment on pipe (10") : full bore rupture-with isolating system	E	Overpressure	0	0	420	0.0	0.0	20.3	Significant
27	Flashfire on piping system : loss of containment on pipe (10") : full bore rupture-without isolating system	E	Thermal	450	450	500	138.0	0.0	24.0	Disastrous
28	Flashfire on piping system : loss of containment on pipe (10") : full bore rupture-with isolating system	E	Thermal	320	320	350	25.4	0.0	0.0	Disastrous
29	Jet fire on piping system : loss of containment on pipe (6") : full bore rupture-without isolating system	E	Thermal	175	190	195	44.4	16.1	25.2	Disastrous
30	Jet fire on piping system : loss of containment on pipe (6") : full bore rupture-with isolating system	D	Thermal	175	190	195	31.8	4.6	4.4	Disastrous
31	UVCE on piping system : loss of containment on pipe (6") : full bore rupture-without isolating system	E	Overpressure	0	0	250	0.0	0.0	42.0	Significant

Dangerous phenomenon n°	Commentaries	Occurrence probability	Effect	Sign. Let. effects	Let. effects	Irrev. effects	Sign. Let. effect	Let. effects	Irrev. effects	Severity category
				m	m	m	People exposed	People exposed	People exposed	
32	UVCE on piping system : loss of containment on pipe (6") : full bore rupture-with isolating system	D	Overpressure	0	0	230	0.0	0.0	32.0	Significant
33	Flashfire on piping system : loss of containment on pipe (6") : full bore rupture-without isolating system	E	Thermal	200	200	220	50.0	0.5	0.0	Disastrous
34	Flashfire on piping system : loss of containment on pipe (6") : full bore rupture-with isolating system	D	Thermal	180	180	200	14.2	0.0	0.0	Disastrous
35	BLEVE on spherical vessel : loss of containment on pressure vessel : Instantaneous release-	E	Thermal	329	464	590	46.5	96.0	113.7	Disastrous

6.2 "Matrice de Mesure de Maîtrise des Risques" (MMR) – Matrix of the measure of risk control (or risk matrix)

The MMR matrix is related to the permit to operate process. This tool can be compared with societal risk. The data used in this matrix is the following:

- occurrence probability of major accidents;
- major accidents severity.

Each identified potential major accident is placed in the risk matrix. Each accident is represented by a number (see Table A2-10).
The next Table presents the risk matrix for the fictive LPG depot.

Table A2-11 Risk matrix for the studied fictive LPG depot

Probability Severity	E	D	C	B	A
Disastrous	1 - 5 – 10 -14 - 18 – 23 – 24 - 27 -28 – 29 – 33 – 35	2 – 6 –30 -34			
Catastrophic	19 – 25	7 -9- 11-15 -16 -17			
Significant	3 – 12 -26 -31	4 -8 -32			
Serious					
Moderate					

According to the French criteria, this case is unacceptable for two reasons:

- There are 4 accidents in the unacceptable area.
- There are more than 5 accidents in the ALARP class 2 areas.

In this case, the operator is asked to propose new risk reduction measures in order to make the situation acceptable.

6.3 "Plan de Prévention des Risques Technologiques » (PPRT) – Technological Risk Prevention Plan

The PPRT is related to land-use and land-use planning. This process is implemented using, among other information, "alea maps". The alea maps can be compared to individual risk.
The PPRT is defined using aléas maps and map of the stakes together with a specific governance process (involving local stakeholders). It has been chosen here not to conduct the whole process of the PPRT. However, we will present the main recommendations for the actual land use and the land use planning that could be given on the basis of aléas maps.
It has to be underlined that as the MMR matrix is not acceptable, before the analysis related to land-use planning, safety improvements have to be implemented. For example, it could be proposed to mount the 700 m^3 sphere of butane. Therefore, effect distances and probabilities of occurrence used in the framework of the PPRT would be significantly lower than the one presented in the following paragraphs.
<u>Note:</u> Since calculations have been realized in the framework of this study, the French regulation has evolved. Some dangerous phenomena are now excluded from the analysis if some specific conditions are respected. These phenomena

concern large pipe ruptures (>DN150) (see [7]). If some conditions are fulfilled, which concern inventory, inspection, maintenance and conception of the pipes, the rupture scenario of these pipes is excluded from PPRT process. Instead, a scenario of 33% leak is retained.
Therefore, if the study would have been realized with regard of this evolution, and if the required condition would be assumed to be fulfilled, the results would be probably less restrictive.

6.3.1 Aléa maps

In order to perform alea maps, the following data related to dangerous phenomena are used:

- kinetic (all dangerous phenomena kinetic are assumed to be "fast");
- occurrence probability;
- effect distances.

The Figure A2-3 presents the "synthesis map of aléas" for the present fictive case. This map synthesizes the "aléa overpressure map" and the "aléa thermal map".

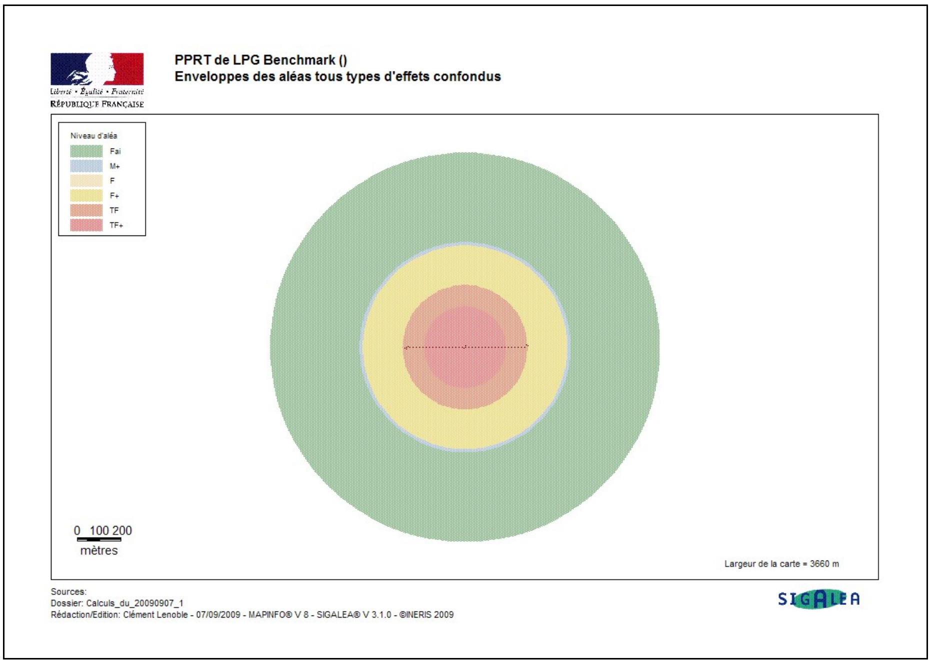


Figure A2-3 Synthesis map of aléas

The distances (radius) of the zones are the following:

Table A2-12 Distances related aléas zones

VH+	180 meters
VH	274 meters
H+	450 meters
M+	464 meters
Low	860 meters

6.3.2 Land-use

On the basis of this aléa map, the following recommendation may be applied for housings:

Table A2-13 Land-use measures which may be apply in the framework of the PPRT

VH+	Expropriation.
VH	Expropriation possible. Relinquishment in the other cases.
H+	Relinquishment.
M+	Improvements of the resistance of structures may be implemented.

6.3.3 Land-use planning

On the basis of this aléa map, the following recommendation may be applied for housings:

Table A2-14 Land-use planning measures which may be apply in the
the
framework of the PPRT

VH+	Ban on new construction
VH	Ban on new construction
H+	Ban on new construction
M+	New constructions possible with some limitations and conditions.
Low	New constructions possible with some minor limitations and conditions.

7. Conclusion

A risk study has been performed by INERIS on the case of a fictive LPG depot.
This study includes the following elements:

- the identification of dangerous phenomena and accidents relevant for the analysis related to the French permit to operate process (MMR) and the land-use planning (PPRT);
- the assessment of their probability of occurrence;
- the assessment of their intensity and their severity;
- the implementation of the risk matrix (MMR);
- the definition and the analysis of the aléa maps (PPRT).

The main conclusions of the study can be summarized as follow:

- **Concerning the permit to operate process:** the implementation of the risk matrix on this fictive case stress an unacceptable situation: 4 accidents are in the unacceptable areas of the matrix, and there are more than 5 accidents in the ALARP class 2 areas. In such situation, the operator would be asked to implement new safety measures in order to improve the safety in its facility.
- **Concerning the PPRT:**
  - it is likely that new constructions would be forbidden in a radius of 450 meters around the facility;
  - in a radius of 860 meters, some restrictions and limitations may be applied on new constructions;
  - in a radius of 274 meters, expropriation is possible;
  - in a radius of 450 meters relinquishment is possible.

Among the classical limits associated to safety reports, there are some specific limits of this study.
At first, the MMR matrix and the aléa maps have been performed using data on a defined fictive facility. However, the MMR matrix shows off that this situation is unacceptable. In the French regulatory context, this statement would lead to safety improvements. Therefore, the effect distances and occurrence probabilities used as a basis for the definition of aléa maps would be significantly lower in a real case. The definition of new safety measures and the assessment of their impact on these parameters are out of the scope of this study. Indeed, if the parameters of the facility would be changed, the comparison with the results RIVM, HSE and FPMs would have been limited.
Secondly, during the realization of this study, the French regulation has evolved. In particular, some dangerous phenomena related to large pipes have been excluded from the land-use planning processes. These evolutions have not been integrated to this study.

8. Références

[1] Loi n°2003-699 du 30 Juillet 2003 relative à la prévention des risques technologiques et naturels et à la réparation des dommages (available in www.ineris.aida.fr);

[2] Arrêté du 10 Mai 2000 relatif à la prévention des accidents majeurs impliquant des substances ou des préparations dangereuses présentes dans certaines catégories d'installations classées pour la protection de l'environnement soumises à autorisation (available in www.ineris.aida.fr);

[3] Arrêté du 29 Septembre 2005 relatif à l'évaluation et à la prise en compte de la probabilité d'occurrence, de la cinétique, de l'intensité des effets et de la gravité des conséquences des accidents potentiels dans les études de dangers des installations classées soumises à autorisation (available in www.ineris.aida.fr);

[4] Circulaire du 29 Septembre 2005 relative aux critères d'appréciation de la démarche de maîtrise des risques d'accidents susceptibles de survenir dans les établissements dits"SEVESO" (available in www.ineris.aida.fr);

[5] Circulaire du 3 Octobre 2005 relative à la mise en œuvre des plans de prévention des plans de prévention des risques technologiques (available in www.ineris.aida.fr);

[6] Circulaire du 28 Décembre 2006 relative à la mise à disposition du guide d'élaboration et de lecture des études de dangers pour les établissements soumis à autorisation avec servitudes et des fiches d'application des textes réglementaires récents (available in www.ineris.aida.fr);

[7] Circulaire du 23 Juillet 2007 relative à l'évaluation des risques et des distances d'effets autour des dépôts de liquides inflammables et des dépôts de gaz inflammables liquéfiés (available in www.ineris.aida.fr);

[8] Ministère de l'écologie, du développement et de l'aménagement durable, Le plan de prévention des risques technologiques, Guide méthodologique, 2005 ;

[9] INERIS, Oméga 5 : Le BLEVE, phénoménologie et modélisation des effets thermique, 2002. (available in www.ineris.fr);

[10] INERIS, Oméga 8 : Feu torche, 2003 (available in www.ineris.fr);

[11] INERIS, Oméga 10: Evaluation des barrières techniques de sécurité, March 2005 (available in www.ineris.fr);

[12] INERIS, Oméga 12 : Dispersion atmosphérique (Mécanismes et outils de calcul), 2002 (available in www.ineris.fr);

[13] INERIS, Oméga 15 : Les éclatements de réservoirs. Phénoménologie et modélisation des effets, 2004 (available in www.ineris.fr);

[14] INERIS, Oméga 20: Démarche d'évaluation des barrières humaines de sécurité, August 2006 (available in www.ineris.fr);

[15] RIVM, INERIS, Benchmark study on flammable liquid depot, 2009.

Annex 3. HSE report LPG comparison study

HSE, report of December 21, 2007.

Benchmark study of a LPG plant

[HSE, December 21, 2007]

A comparison of the QRA approach of HSE, CEV and INERIS

Introduction

For pressurised flammable risks does not carry out quantified risk assessments for land use planning. HSE uses a protection based concept approach based on the hazard from the flammable substance.

QRA is used for the societal risk assessments, but the methods used are not currently employed other than for internal developments. This may change in the future.

Although specific details concerning the plant etc were provided, HSE has followed its own policies and procedures for some of these items. For example, the duration of releases used in the analysis are those used routinely in HSE rather than the specific values presented in the brief.

For this study, what HSE has done and will present in this document is threefold:

(a) the current protection based assessment resulting in three contours which are used in the land use planning system;
(b) the internally developed method for determining societal risks; and
(c) an internally developed method for determining individual risk of death contours.

Assumptions used

Based on the population grid used in this study, the items of relevant plant have been located at the following:

Mounded vessel 1 x = 14690, y = 14790
Mounded vessel 2 x = 14690, y = 14690
Sphere x = 14690, y = 14890
Tanker 1 x = 14965, y = 14790
Tanker 2 x = 14434, y = 14788
Tanker 3 x = 14399, y = 14797

For the societal risk calculations the spreadsheet considers the following scenarios:

BLEVE from vessels and tankers.
Releases from pipework resulting in flash fire and jet fires.
Coupling releases resulting in jet fires and flash fires.
Instantaneous and continuous releases from the butane sphere resulting in flash fire.

Releases from pipework are assumed to be at a flow rate of 40 kgs/sec at a frequency of 0.5 chances per million per metre.
Releases from couplings are assumed to be at a flow rate of 8.4 kgs/sec at a frequency of 1.5 chances per million per operation.
All continuous releases are assumed to be for 30 minutes, except for coupling releases which are reduced to 5 minutes. (These are HSE normal assumptions)

Protection based concept

The land use planning zones around this hypothetical LPG depot have been calculated as for a new hazardous substances consent application.

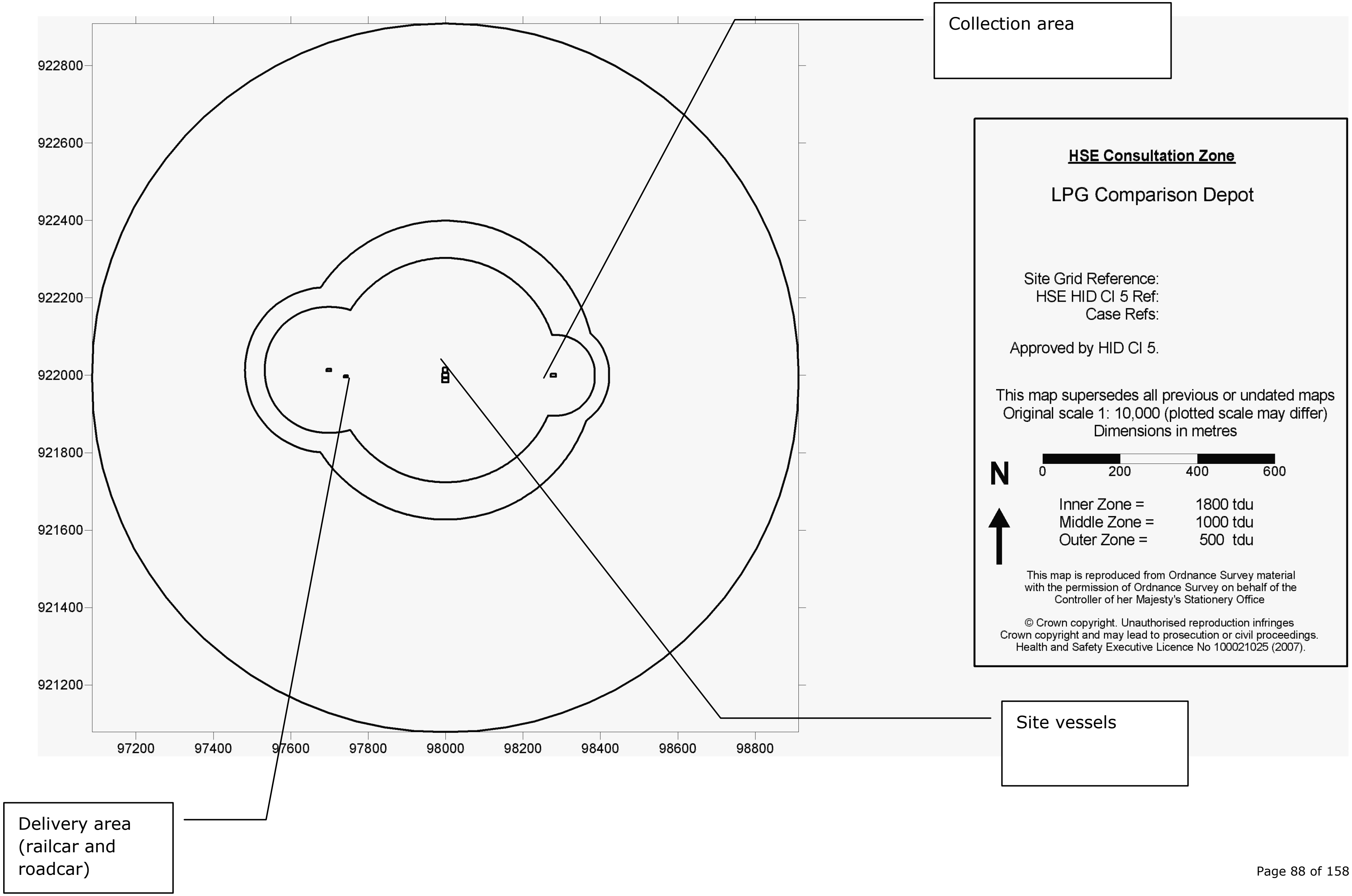
A hazard calculation has been made using FLAMCALC6 to provide a protection concept based assessment.

			Distance from vessel boundary (m)		
Vessel	Substance	Capacity (tonnes)	Inner zone (1800 tdu[2])	Middle zone (1000 tdu)	Outer zone (500 tdu)
Collection roadcar	Propane	47 (21.4)	100	137	186
Delivery roadcar	n-Butane	47 (25.4)	109	148	200
Delivery railcar	Propane	119 (54.3)	159	210	282
Mounded bullet	Propane	2500 (1140)	mounded	mounded	901
Surface sphere	n-Butane	700 (378)	283	379	509

Note: The only scenario taken in this approach is BLEVE. Because the bullets are mounded, it is HSE policy to base the inner and middle zones on BLEVE calculation of the tankers. The outer zone is based on the BLEVE of the surface sphere.

These distances are overlaid to generate the following 3-zone map.

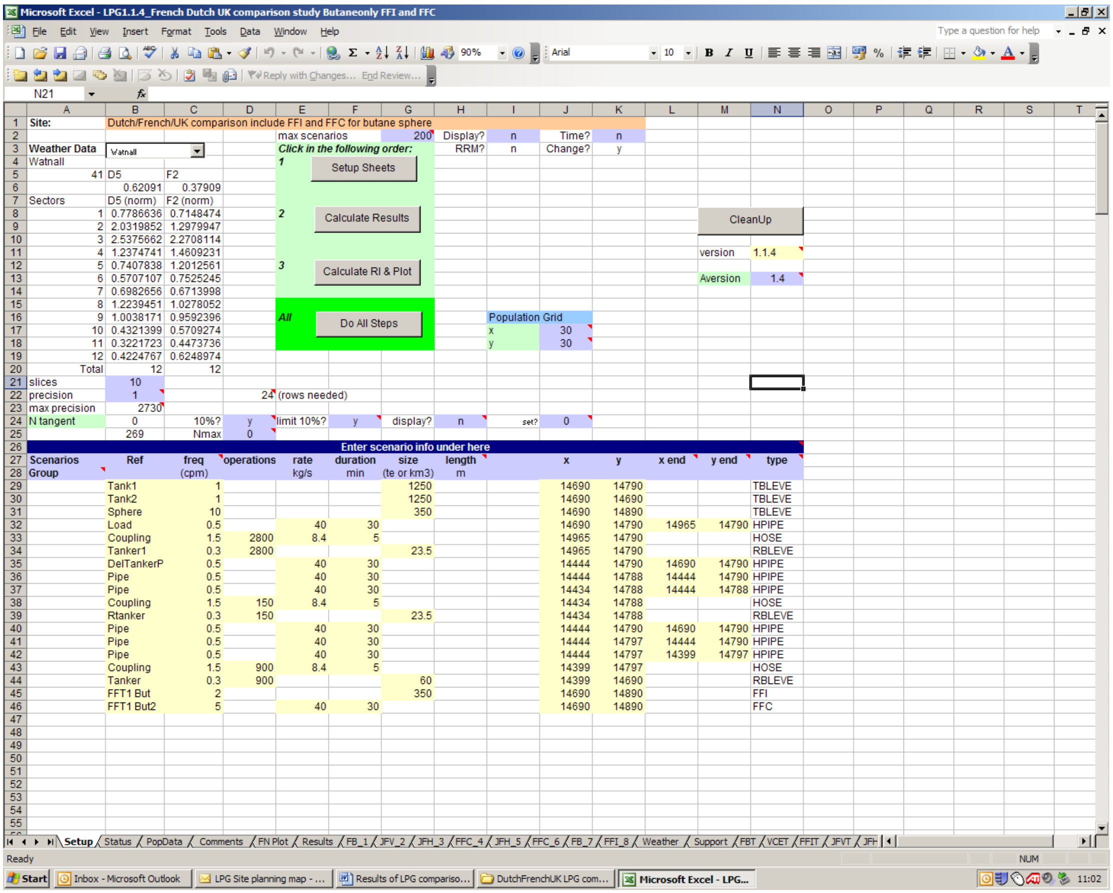
[2] tdu = thermal dose unit. Units of $(kW/m^2)^{4/3}$.sec


Collection area
Site vessels
Delivery area (railcar and roadcar)
922800
922600
922400
922200
922000
921800
921600
921400
921200
97200
97400
97600
97800
98000
98200
98400
98600
98800
HSE Consultation Zone
LPG Comparison Depot
Site Grid Reference:
HSE HID CI 5 Ref:
Case Refs:
Approved by HID CI 5.
This map supersedes all previous or undated maps
Original scale 1: 10,000 (plotted scale may differ)
Dimensions in metres
N
0
200
400
600
Inner Zone = 1800 tdu
Middle Zone = 1000 tdu
Outer Zone = 500 tdu
This map is reproduced from Ordnance Survey material with the permission of Ordnance Survey on behalf of the Controller of her Majesty's Stationery Office
© Crown copyright. Unauthorised reproduction infringes Crown copyright and may lead to prosecution or civil proceedings. Health and Safety Executive Licence No 100021025 (2007).

Societal risk calculations

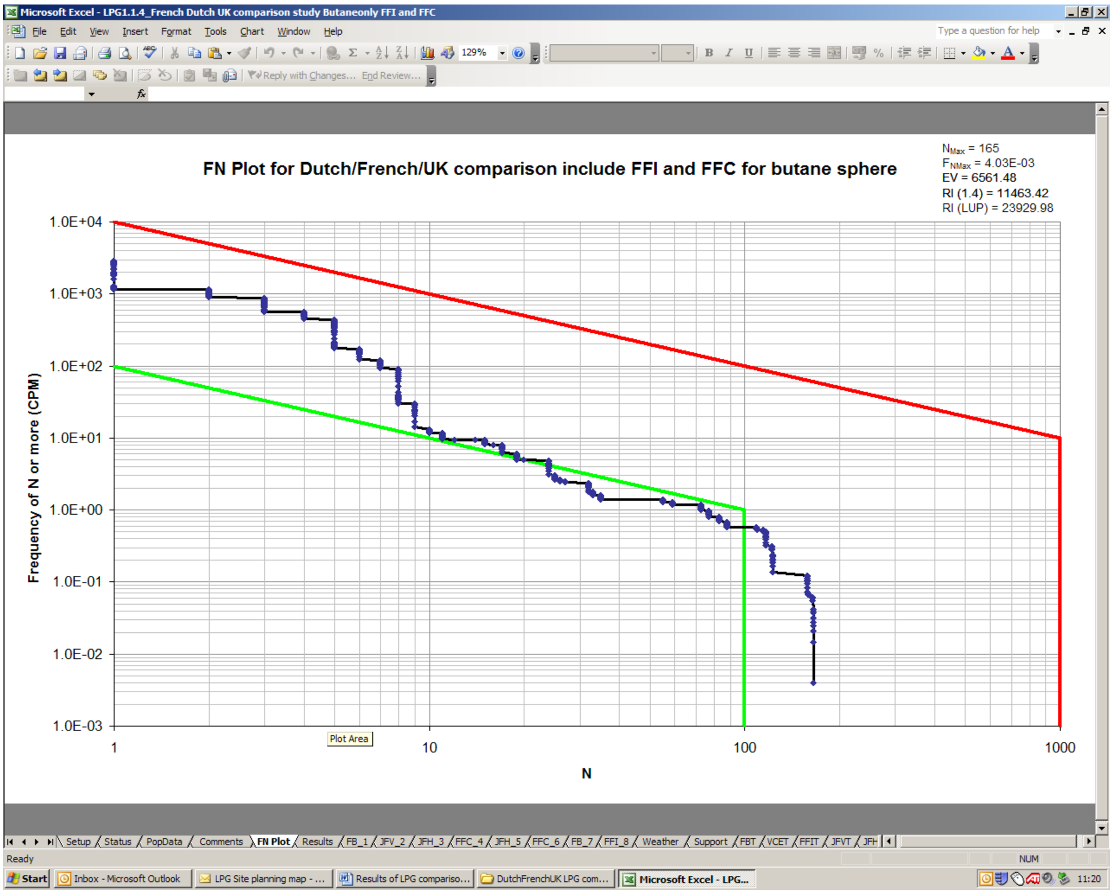
The societal risk calculations have been carried out using HSE spreadsheet tools – a development tool at present.

The following screen shot indicates the scenarios and assumptions made:



Scenarios Group	Ref	freq (cpm)	operations	rate kg/s	duration min	size (te or km3)	length m	x	y	x end	y end	type
	Tank1	1				1250		14690	14790			TBLEVE
	Tank2	1				1250		14690	14690			TBLEVE
	Sphere	10				350		14690	14890			TBLEVE
	Load	0.5		40	30			14690	14790	14965	14790	HPIPE
	Coupling	1.5	2800	8.4	5			14965	14790			HOSE
	Tanker1	0.3	2800			23.5		14965	14790			RBLEVE
	DelTankerP	0.5		40	30			14444	14790	14690	14790	HPIPE
	Pipe	0.5		40	30			14444	14788	14444	14790	HPIPE
	Pipe	0.5		40	30			14434	14788	14444	14788	HPIPE
	Coupling	1.5	150	8.4	5			14434	14788			HOSE
	Rtanker	0.3	150			23.5		14434	14788			RBLEVE
	Pipe	0.5		40	30			14444	14790	14690	14790	HPIPE
	Pipe	0.5		40	30			14444	14797	14444	14790	HPIPE
	Pipe	0.5		40	30			14444	14797	14399	14797	HPIPE
	Coupling	1.5	900	8.4	5			14399	14797			HOSE
	Tanker	0.3	900			60		14399	14690			RBLEVE
	FFT1 But	2				350		14690	14890			FFI
	FFT1 But2	5		40	30			14690	14890			FFC

The results of the above, in the form of an FN curve is:



Nmax = the number estimated to be killed = 165

The risk integral (RI) is 11463 (compared to our criteria of RI = 2000 for broadly acceptable risks; and RI = 500 000 for 'intolerable' risks).

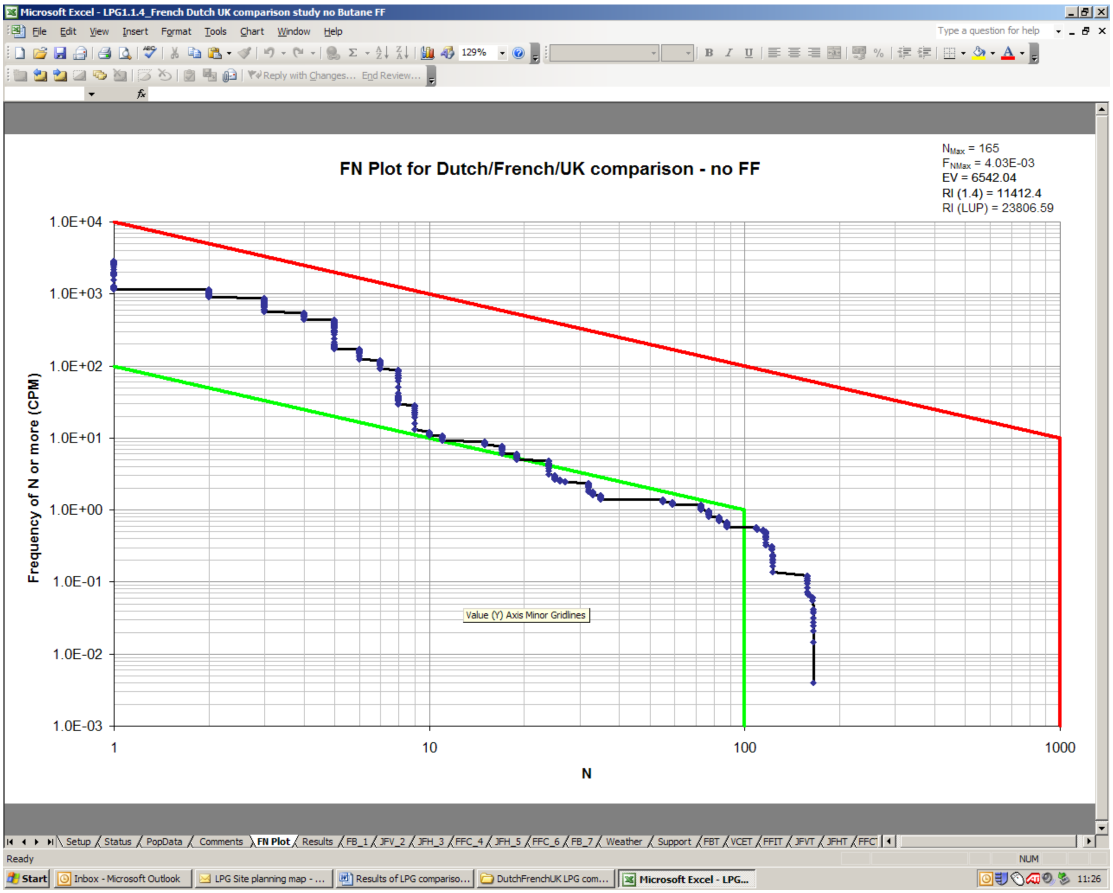
The expectation value or PLL = 6561

We have also calculated the societal risks by removing various scenarios to determine which scenarios contribute most to the risk.

For example, removing the flash fire scenarios from the butane vessel results in:

Nmax = 165
RI = 11412
EV = 6542

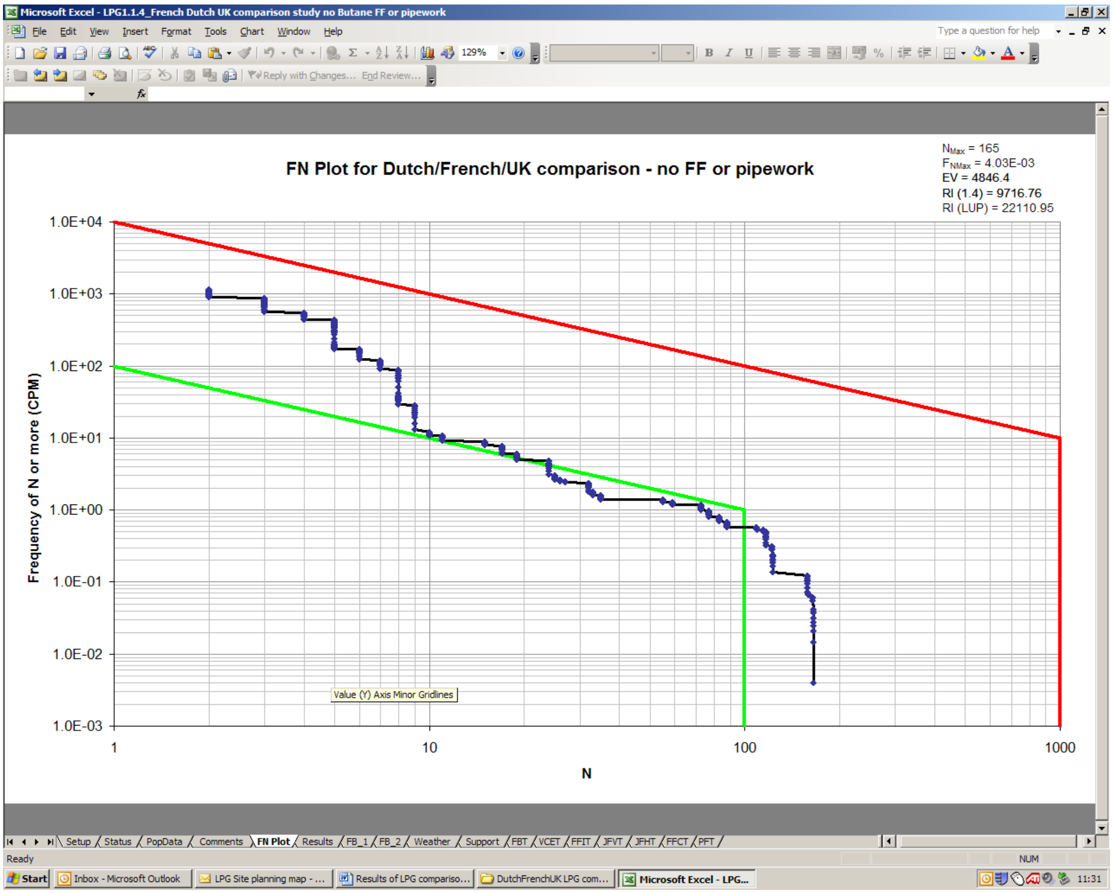
Ie essentially zero contribution from the butane sphere flash fires.



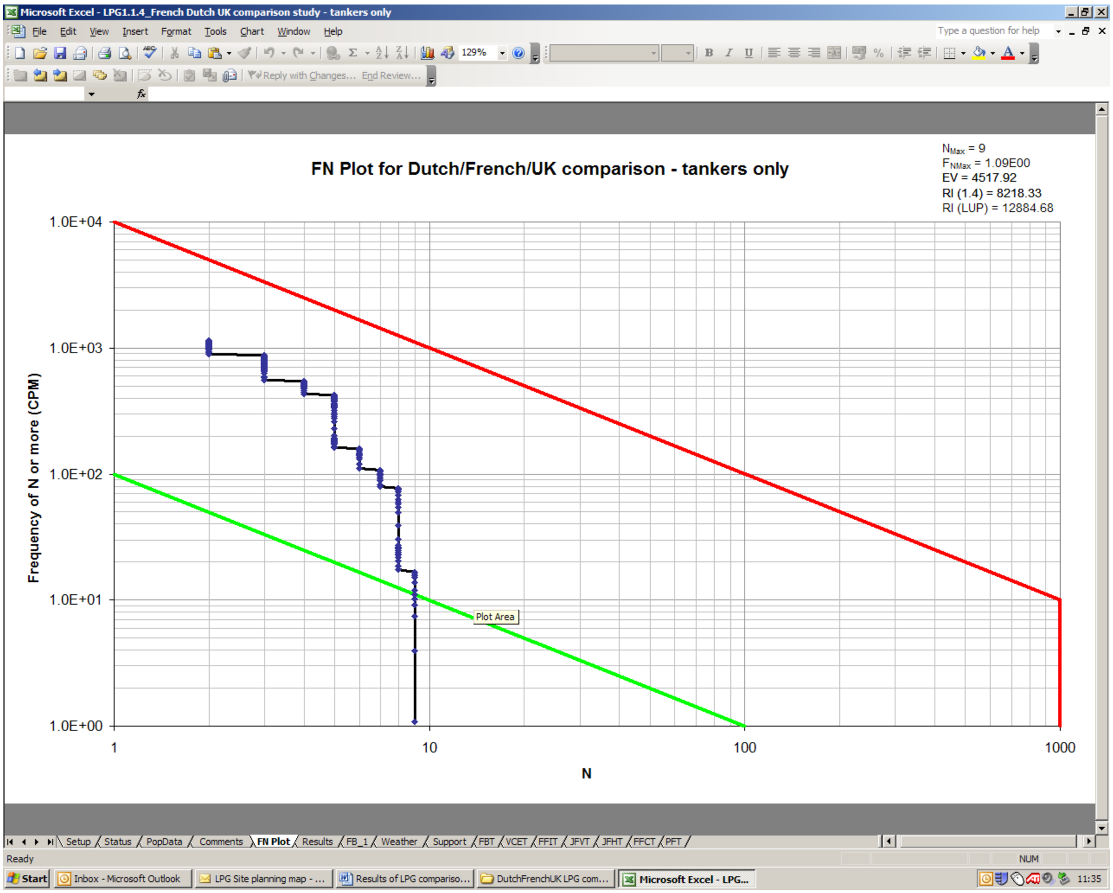
Similarly, removing the butane sphere flash fire scenarios and all the pipework scenarios results in:

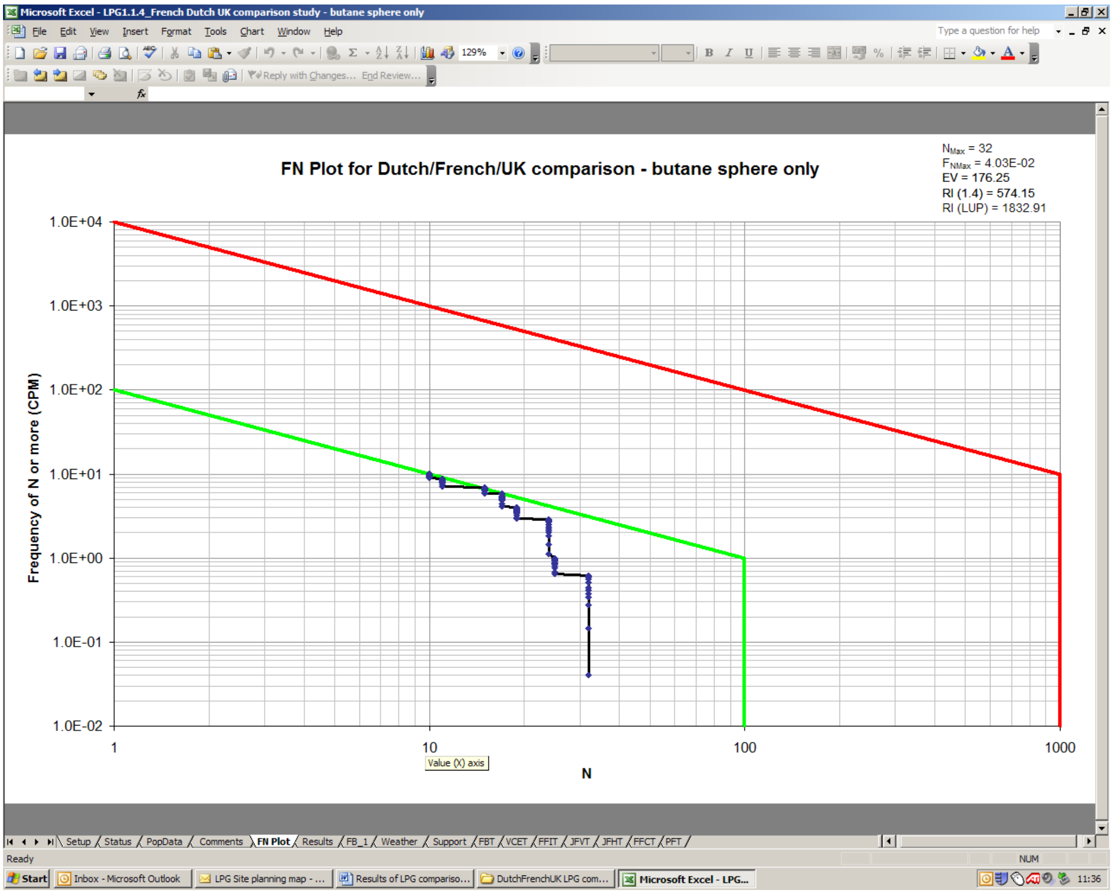
Nmax = 165
RI = 9716
EV = 4846

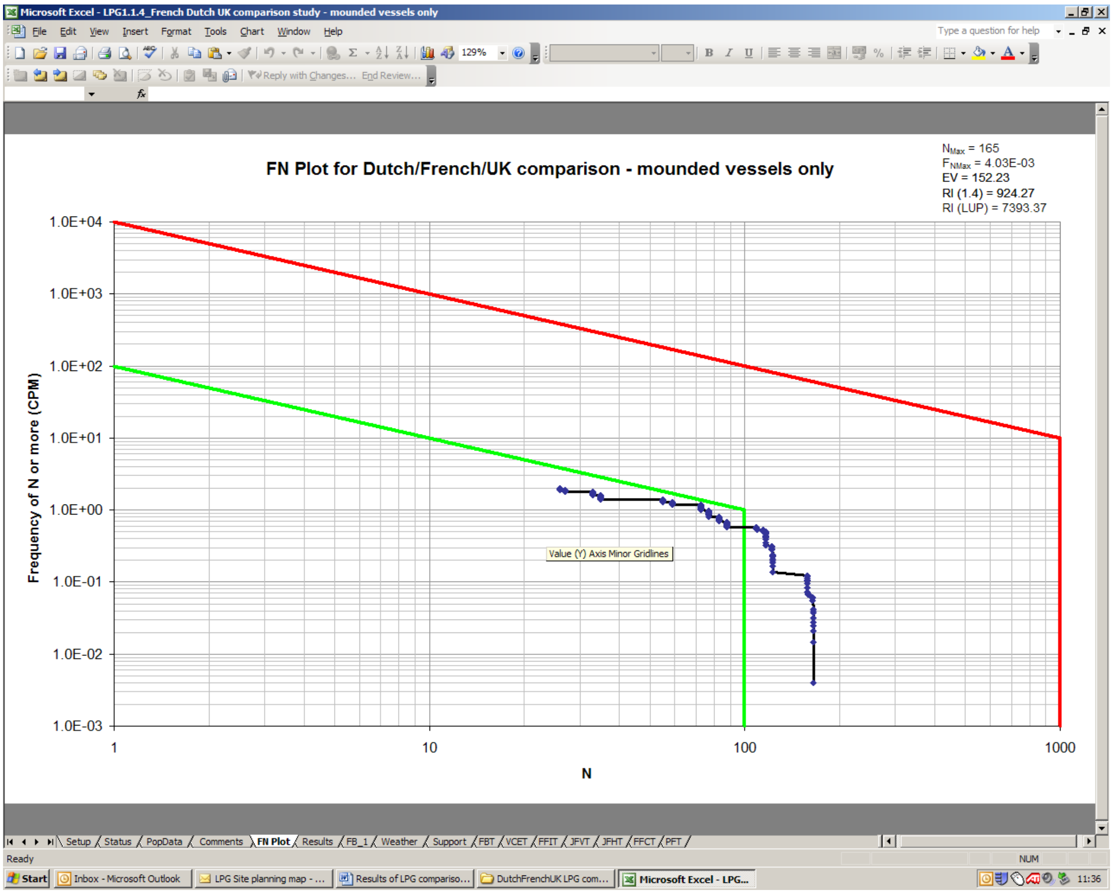
As expected the pipework releases are short range effects that only alter the FN curve at low N.



The following screenshots show the FN curves for BLEVE of tankers only; butane sphere only; and mounded vessels only.


Microsoft Excel - LPG1.1.4_French Dutch UK comparison study - tankers only
FN Plot for Dutch/French/UK comparison - tankers only
N_{Max} = 9
F_{NMax} = 1.09E00
EV = 4517.92
RI (1.4) = 8218.33
RI (LUP) = 12884.68
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
Frequency of N or more (CPM)
1
10
100
1000
N
Plot Area


Microsoft Excel - LPG1.1.4_French Dutch UK comparison study - butane sphere only
FN Plot for Dutch/French/UK comparison - butane sphere only
N_Max = 32
F_NMax = 4.03E-02
EV = 176.25
RI (1.4) = 574.15
RI (LUP) = 1832.91
Frequency of N or more (CPM)
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-01
1.0E-02
1
10
100
1000
Value (X) axis
N



These FN curves illustrate how a very good determination of the societal risks can be achieved by only considering the major release scenarios ie BLEVE especially for use in land use planning, which makes the assessment significantly less resource intensive.

Individual risk of death assessment

Purely for this comparison study HSE have developed an individual risk spreadsheet which is essentially identical to the societal risk spreadsheets. It is very user unfriendly at this time but has been used to illustrate the 3-zones.

The scenarios taken are identical to those used in the societal risk studies. We have also carried out individual risk contours on a reduced scenario set ie tankers and vessels only; vessels only; and tankers only.

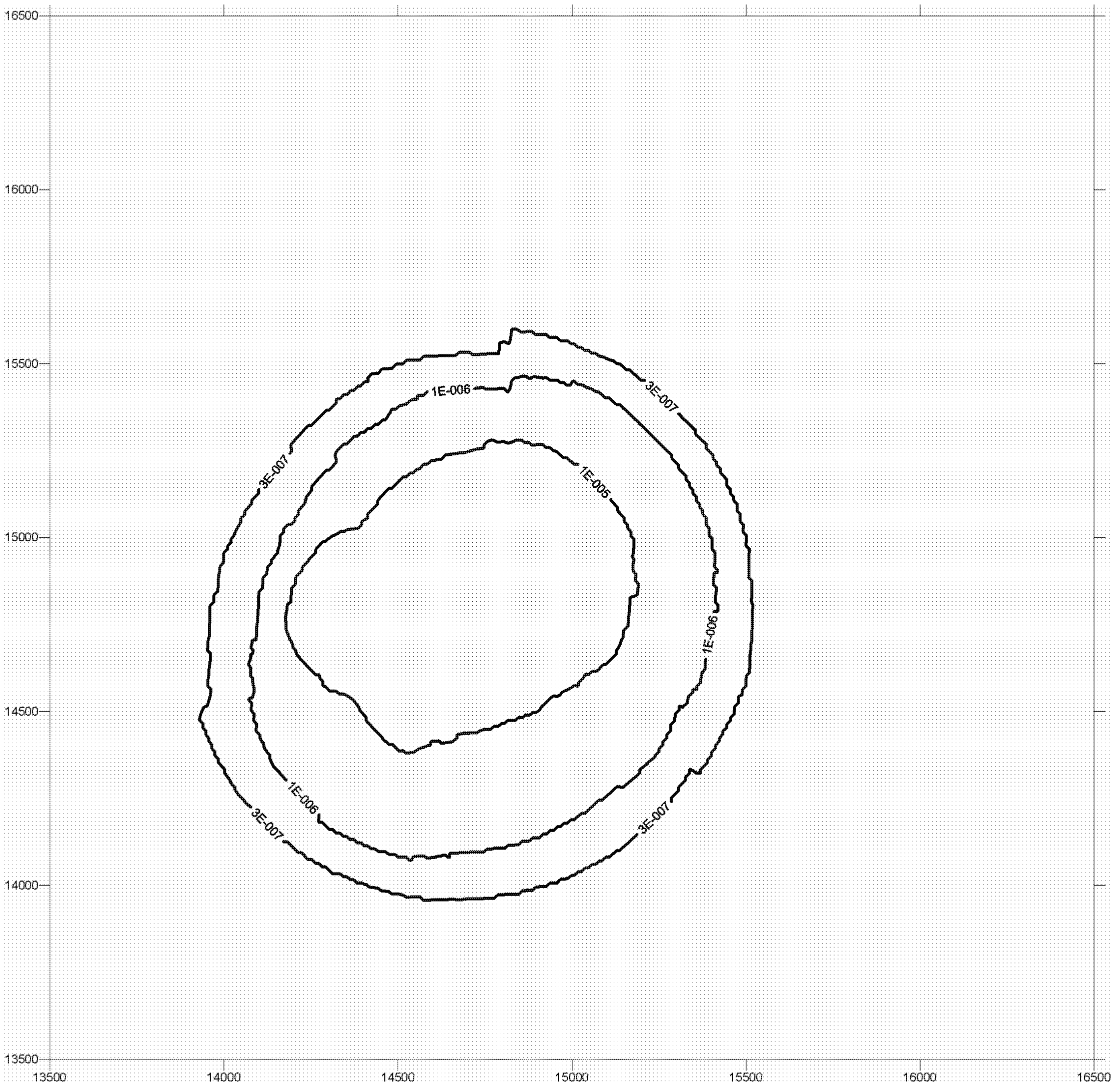


Figure A3-1 Full scenario

Tank1	1			1250	1469014790	TBLEVE
Tank2	1			1250	1469014690	TBLEVE
Sphere	10			350	1469014890	TBLEVE
Load	0.5	40	30		14690147901496514790	HPIPE
Coupling	1.528008.4		5		1496514790	HOSE
Tanker1	0.32800			23.5	1496514790	RBLEVE
DelTankerP	0.5	40	30		14444147901469014790	HPIPE
Pipe	0.5	40	30		14444147881444414790	HPIPE
Pipe	0.5	40	30		14434147881444414788	HPIPE
Coupling	1.5	1508.4	5		1443414788	HOSE
Rtanker	0.3	150		23.5	1443414788	RBLEVE
Pipe	0.5	40	30		14444147901469014790	HPIPE
Pipe	0.5	40	30		14444147971444414790	HPIPE
Pipe	0.5	40	30		14444147971439914797	HPIPE
Coupling	1.5	9008.4	5		1439914797	HOSE
Tanker	0.3	900		60	1439914797	RBLEVE
FFT1 But	2			350	1469014890	FFI
FFT1 But2	5	40	30		1469014890	FFC

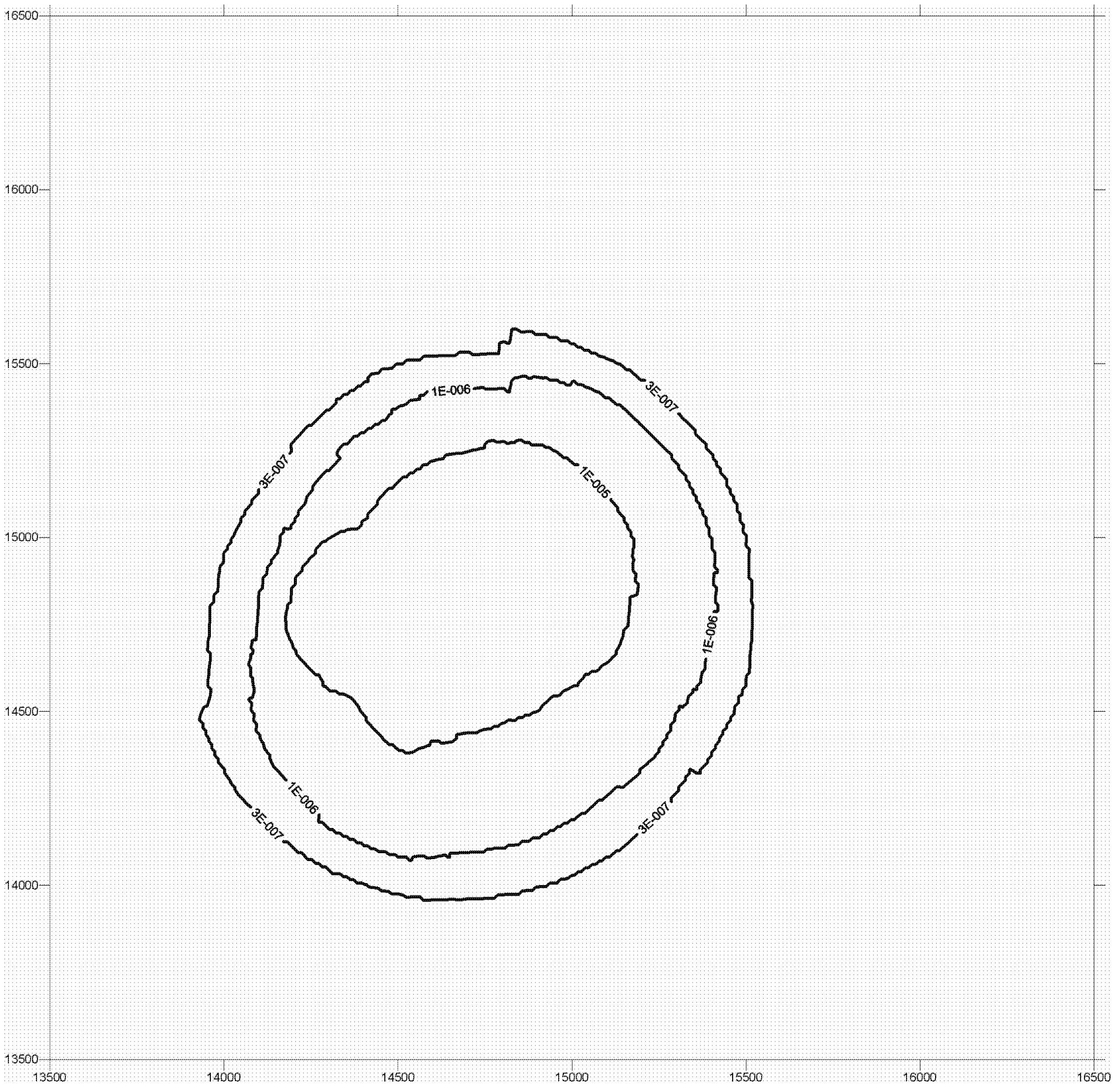


Figure A3-2 Tankers and Vessels

Tank1	1		1250	1469014790	TBLEVE
Tank2	1		1250	1469014690	TBLEVE
Sphere	10		350	1469014890	TBLEVE
Tanker1	0.32800		23.5	1496514790	RBLEVE
Rtanker	0.3	150	23.5	1443414788	RBLEVE
Tanker	0.3	900	60	1439914797	RBLEVE

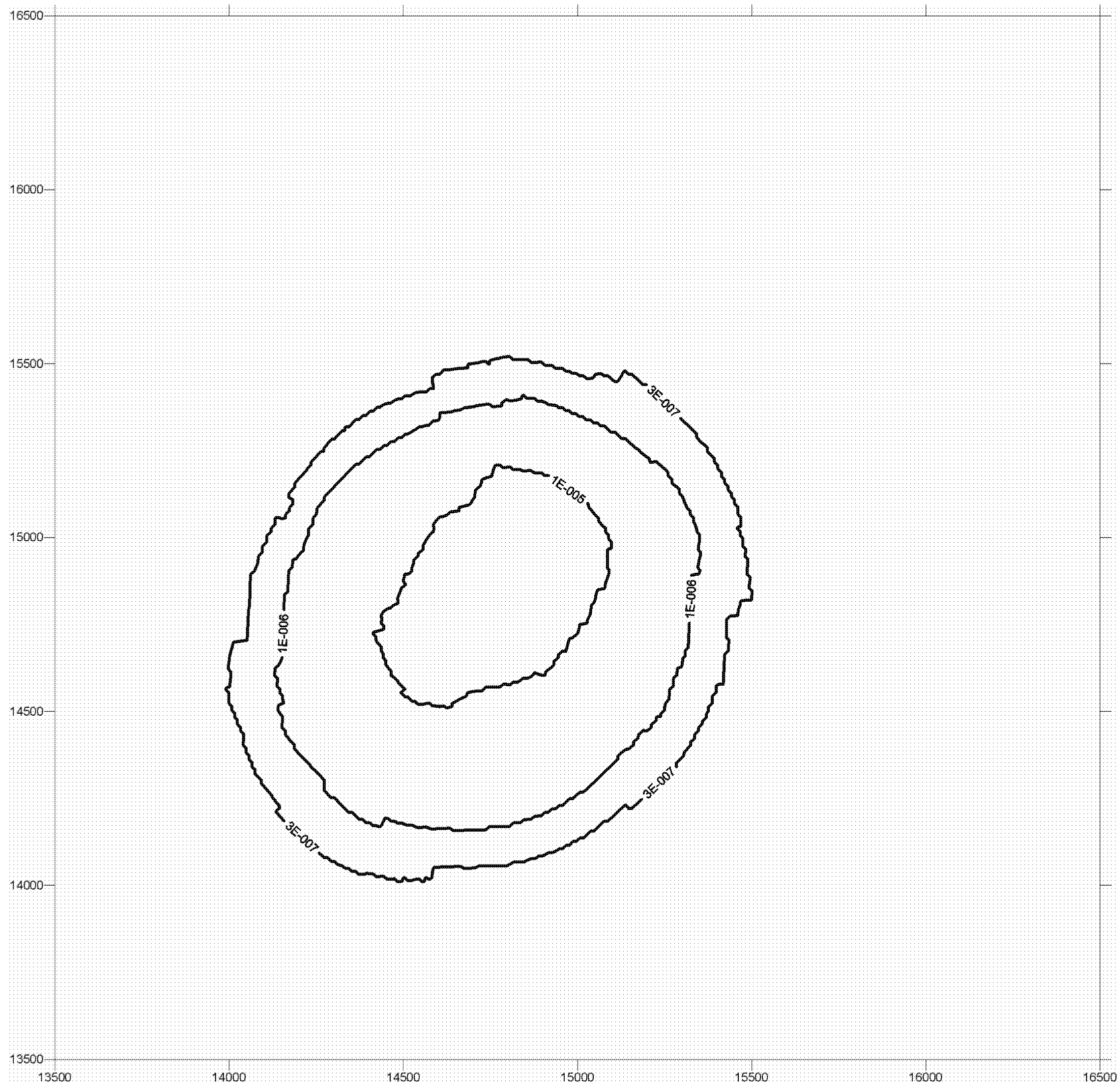


Figure A3-3 Vessels

Tank1	1	1250	1469014790	TBLEVE
Tank2	1	1250	1469014690	TBLEVE
Sphere	10	350	1469014890	TBLEVE

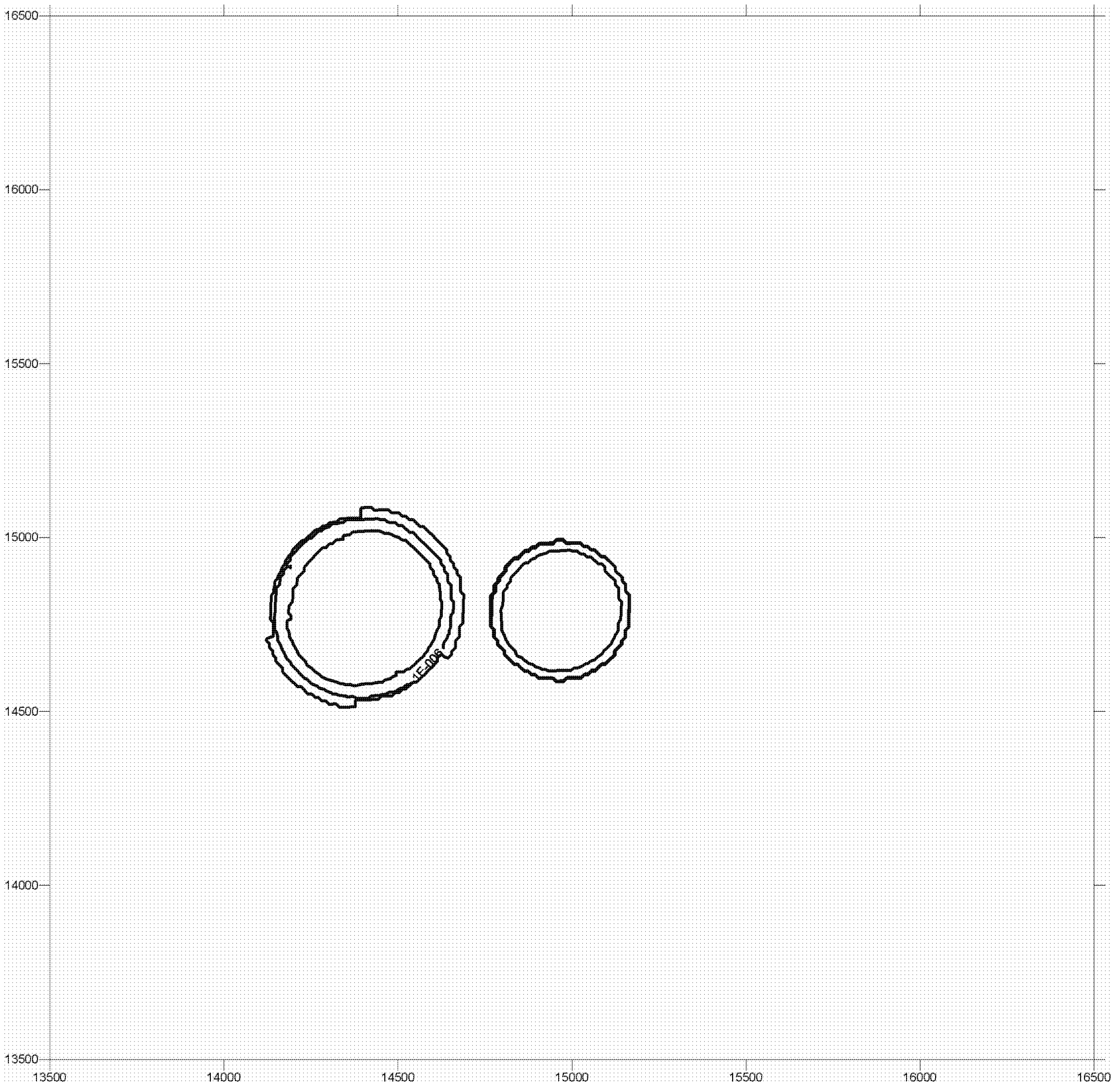


Figure A3-4 Tankers

Tanker1	0.32800	23.5	1496514790	RBLEVE
Rtanker	0.3 150	23.5	1443414788	RBLEVE
Tanker	0.3 900	60	1439914797	RBLEVE

Annex 4. RIVM report LPG comparison study

RIVM, November 7, 2007.

Benchmark study of a LPG plant

A comparison of the QRA approach of HSE, CEV and INERIS

Rev. 0

RIVM-CEV

L. Gooijer

Date: November 7, 2007

Contents

1. Introduction

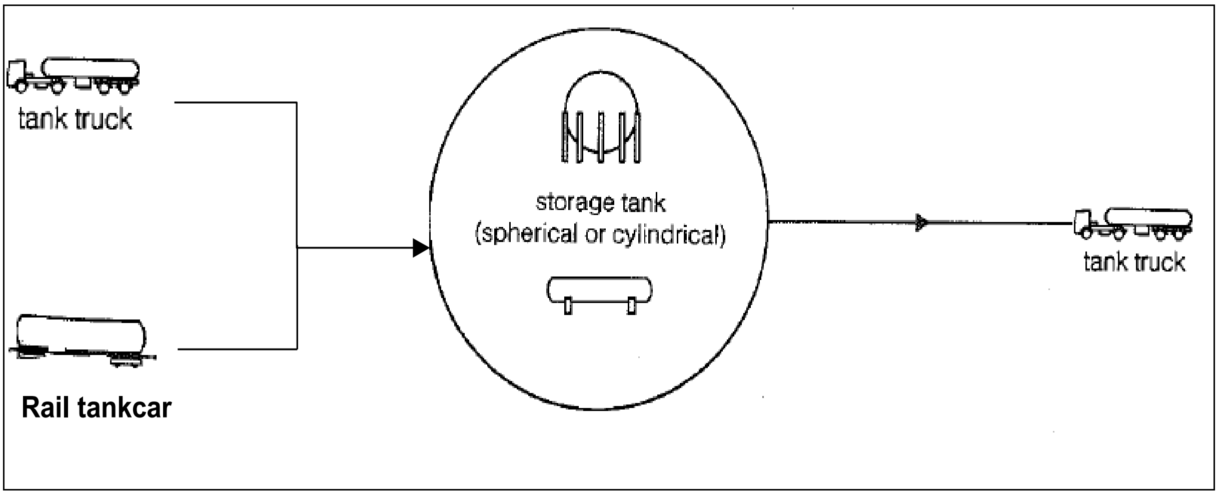
In order to compare the Quantitative Risk Assessment (QRA) method in the United Kingdom (HSE), France (INERIS) and the Netherlands (RIVM) a benchmark exercise is performed for a fictive LPG plant. This report contains the results of the calculations. The calculations have been based on the site description (chapter 2) and the scenario list (chapter 3). Chapter 4 describes some modeling aspects. The results of the calculations are shown in chapter 5.

2. General site description

The site description of the LPG plant has been made by INERIS (LPG depot, 30-08-2007). RIVM and INERIS had some communications of this description and the last revision (containing some questions and answers) is dated September 25, 2007. For the whole description containing the detail information we refer to the document of September 25.

2.1 Main installations

At the LPG plant LPG (propane and butane) can be loaded and unloaded in and from rail tank cars and road tankers and stored in vessels. The Figure shows the main installations of the LPG establishment.



The LPG depot that is studied is made of:

- 2 cylindrical vessels in mounds (for propane) - Capacity : 2500 m^3 per vessel;
- 1 spherical vessels (for butane) - Capacity : 700 $m^{3;}$
- 3 rail tankcar unloading stations (2 unloading arms for each station: one for the liquid line and one for the vapour line);
- 2 road tanker stations: 1 loading station with one arm for propane and 1 loading/unloading station for both propane and butane with two arms (one arm for the liquid line and one arm for the vapour line);
- A piping system equipped with:
    - 2 pumps for the road tanker loading station (propane);

- o 1 pump for the road tanker loading station (butane);
- o 1 compressor.

2.2 (Un)loading capacities

In the table below an overview is given of the throughput and the (un)loading capacities.

	Product	Capacity (m^3)	Flow rate (m^3/h)	Filling rate	Number of un(loading) per year	Duration (total time staying)
Loading the road tanker	Propane	21	60	85%	2750	In average 20 minutes
	Propane	47	60	85%	15	
	Butane	21	60	85%	35	
Unloading the road tanker	Propane	47	60	85%	135	1 hour
	Butane	47	60	85%	15	1 hour
Unloading rail tankcar	Propane	119	100	85%	900	2 hours

For the duration of the (un)loading activities (scenario 'failure' or 'leakage' of the loading arm) RIVM used the combination of the capacity and the flow rate. For the scenarios concerning the road tanker or rail tankcar itself, RIVM used the given duration of the 'total time staying'. The only exception is the duration of the road tanker propane of 47 m^3. In that case RIVM used the duration of 1 hour in stead of the given average of 20 minutes.

2.3 Safety measurements

The following safety measurements are available:

- Gas detection: when gas is detected all remote controlled valves are closed automatically and the loading process will be stopped.
- Emergency stop: by activating the emergency stop all remote controlled valves are closed automatically and the loading process will be stopped. To take this into account we assume an operator is present during the (un)loading process.

The closing time and the failure upon demand of the safety systems are in accordance with the Dutch guidelines.

Safety system	Failure upon demand	Closing time
Gas detection	0.001 per demand	120 s
Emergency stop	0.1 per demand	120 s

These two systems give four different options. When both systems fail, the duration of the scenario is 1800 s (maximum duration). When one (or both) of the systems reacts, the closing time is 120 s. So we consider two options:

Option	Frequency (upon demand)	Closing time
1. Both systems fails	0.0001	1800 s
2. One or both system(s) react(s)	1 (0,9999)	120 s

The two systems are just taken into account at scenarios concerning (un)loading activities:

- catastrophic failure of a pump;
- rupture of a line;
- rupture of (un)loading arms.

3. Scenario list

3.1 Introduction

The scenarios have been based on the description in the new Dutch guideline CPR 18 (Handleiding Risicoberekeningen BEVI, rev. 1.4, July 2007). For the elaboration of the scenarios the next remarks are made:

- The maximum duration of a scenario is 1800 s.
- For the scenarios concerning lines propane is used.
- The vapor (return) lines (inclusive the compressor) are ignored. In generally, the contribution to the external risks is not significant.

3.2 Vessels propane

Scenarios for pressure vessel	Amount (m^3)	Rate (kg/s)	Duration (s)	Initial frequency (y^-)	Frequency 2 vessels (y^-)
Instantaneous release	2125	2125 m^3	inst.	5.0E-07	1.0E-06
Continuous release of the complete inventory in 10 min.	2125	1800 kg/s	600	5.0E-07	1.0E-06
Continuous release from a hole with a diameter of 10 mm	2125	1.4 kg/s	1800	1.0E-05	2.0E-05

Remarks

- There are 2 storage vessels propane.
- The volume of both vessels is 2500 m^3. The filling rate is maximum 85%.
- The vessels are mounded vessels. That means the event of a BLEVE will be ignored.

Scenario for pressure relief valve	Rate (kg/s)	Duration (s)	Initial frequency (y^-)	Frequency 2 valves (y^-)
Discharge with max discharge rate	25 kg/s	1800	2.0E-05	4.0E-05

Remarks
- There are 2 pressure relief valves.
- The maximum flow rate is 160 m^3/h (about 25 kg/s).
- The release direction is vertical and the elevation at 2 meter.

3.3 Vessel butane

Scenarios for pressure vessel	Amount (m3)	Rate (kg/s)	Duration (s)	Initial frequency (y^-)	Frequency 1 vessel (y^-)
Instantaneous release	385	385 m^3	inst.	5.0E-07	5.0E-07
Continuous release of the complete inventory in 10 min.	385	370 kg/s	600	5.0E-07	5.0E-07
Continuous release from a hole with a diameter of 10 mm	385	0,6 kg/s	1800	1.0E-05	1.0E-05

Remarks
- There is 1 storage vessel butane.
- The volume is 700 m^3. The filling rate is maximum 55%.
- One of the events of an instantaneous release is a Bleve (vessel is not mounded). The burst pressure is 12 bar (gauge).

Scenario for pressure relief valve	Rate (kg/s)	Duration (s)	Initial frequency (y^-)	Frequency 2 valves (y^-)
Discharge with max discharge rate	0.02 kg/s	1800	2.0E-05	4.0E-05

Remarks
- There are 2 pressure relief valves.
- The maximum flow rate is unknown; the pressure setting is 9.7 bars.
- The release direction is vertical and the elevation at 2 meter.

3.4 Pumps

Pumps propane
For the loading of propane there are 2 pumps. In the QRA RIVM considers centrifugal pump without additional provisions.

Scenario for pumps	Rate (kg/s)	Duration (s)	Time fraction	Safety system	Initial frequency (y^-)	Frequency 2 pumps (y^-)
Catastrophic failure	239 kg/s	120 + 13	11%	1	1.0E-04	2.1E-05
Catastrophic failure	239 kg/s	1800	11%	1E-4	1.0E-04	2.1E-09
Leak (10%D)	8.7 kg/s	1800	11%	-	4.4E-03	9.3E-04

Remarks

- Catastrophic failure is modeled as a full bore rupture. The release rate is 239 kg/s (rupture at 55 m, diameter is 10 inch).
- When the safety systems react the closing time is 120 s. But we also considered the amount of the line blocked (vessel-station). The amount is 3200 kg what results in a duration of plus 13 s.
- Time fraction: There are 2750 deliveries of 21 m^3 road tanker propane per year with a duration of 20 minutes and 15 deliveries of 47 m^3 propane with a duration of 40 minutes. Together it is 11% of the time.
- Safety system: see paragraph 2.3.

Pump butane

For the loading of butane there is 1 pump. In the QRA RIVM considers centrifugal pump without additional provisions.

Scenario for pumps	Rate (kg/s)	Duration (s)	Time fraction	Safety system	Initial frequency (y^{-})	Frequency 1 pump (y^{-})
Catastrophic failure (safety system reacts)	129 kg/s	120 + 29	0.1%	1	1.0E-04	1.3E-07
Catastrophic failure (safety system fails)	129 kg/s	1800	0.1%	1E-4	1.0E-04	1.3E-11
Leak (10%D)	3.9 kg/s	1800	0.1%	-	4.4E-03	5.9E-06

Remarks

- Catastrophic failure is modelled as a full bore rupture. The release rate is 129 kg/s (rupture at 55 m, diameter is 10 inch).
- When the safety systems react the closing time is 120 s. But we also considered the amount of the line blocked (vessel-station). The amount is 3700 kg butane what results in a duration of plus 29 s.
- Time fraction: There are 35 deliveries of 21 m^3 road tanker butane per year with a duration of 20 minutes.
- Safety system: see paragraph 2.3.

3.5 Road tanker unloading station

Unloading road tanker propane (47 m^3)

Scenarios for road tanker	Rate (kg/s)	Duration (s)	Time fraction	Safety system	Initial frequency	Frequency (y^{-1})
Instantaneous release	40 m^3	inst.	1.5 %	-	5.0E-07 y^{-1}	7.7E-09
Continuous release from the largest connection (diameter 3 inch)	78 kg/s	255	1.5 %	-	5.0E-07 y^{-1}	7.7E-09
Rupture arm (3 inch) (safety system operates)	13 kg/s	120 s	90 h	1	3.0E-08 h^{-1}	2.7E-06
Rupture arm (3 inch) (safety system fails)	13 kg/s	1800 s	90 h	1E-4	3.0E-08 h^{-1}	2.7E-10
Leak of the (un)loading arm (10% of the diameter)	0.8 kg/s	1800 s	90 h	-	3.0E-07 h^{-1}	2.7E-05
BLEVE	40 m^3	-	90 h	-	5.8E-10 h^{-1}	5.2E-08

Remarks

- The volume is 47 m^3. The filling rate is 85%.
- The diameter is 3 inch.
- Time fraction:
  - The presence of the road tanker on the site is 1 hour. There are 135 deliveries, so the time fraction is 1.5% (presence of the road tanker).
  - The flow rate is 60 m^3/h. Based on a volume of 40 m^3 the unloading duration is 40 minutes. There are 135 deliveries, so the time fraction is 90 hours per year (unloading activity).
- The flow rate of the unloading activity is 60 m^3/hour. For the rupture of the unloading arm the outflow is 150% of the mean flow rate (according to the Dutch guidelines). This results in a flow rate of 13 kg/s propane.
- Safety system: see paragraph 2.3.
- BLEVE: the burst pressure of the BLEVE is 23.5 bar (gauge).

Unloading road tanker butane (47m^3)

Scenarios for road tanker	Rate (kg/s)	Duration (s)	Time fraction	Safety system	Initial frequency	Frequency (y^{-})
Instantaneous release	40 m^3	inst.	0.2 %	-	5.0E-07 y^{-1}	8.6E-10
Continuous release from the largest connection (diameter 3 inch)	34 kg/s	682 s	0.2 %	-	5.0E-07 y^{-1}	8.6E-10
Rupture arm (3 inch) (safety system operates)	15 kg/s	120 s	10 h	1	3.0E-08 h^{-1}	3.0E-07
Rupture arm (3 inch) (safety system fails)	15 kg/s	1800 s	10 h	1E-4	3.0E-08 h^{-1}	3.0E-11
Leak of the (un)loading arm (10% of the diameter)	0.3 kg/s	1800 s	10 h	-	3.0E-07 h^{-1}	3.0E-06
BLEVE	40 m^3	-	10 h	-	5.8E-10 h^{-1}	5.8E-09

Remarks

- The volume is 47 m^3. The filling rate is 85%.
- The diameter is 3 inch.
- Time fraction:
  - The presence of the road tanker on the site is 1 hour. There are 15 deliveries, so the time fraction is 0.2 % (presence of the road tanker).
  - The flow rate is 60 m^3/h. Based on a volume of 40 m^3 the unloading duration is 40 minutes. There are 15 deliveries, so the time fraction is 10 hours per year (unloading activity).
- The flow rate of the unloading activity is 60 m^3/hour. For the rupture of the unloading arm the outflow is 150% of the mean flow rate (according to the Dutch guidelines). This results in a flow rate of 15 kg/s butane.
- Safety system: see paragraph 2.3.
- BLEVE: the burst pressure of the BLEVE is 23.5 bar (gauge).

3.6 Rail tank car unloading station

Unloading rail tank car propane (119 m^3)

Scenarios for rail tankcar	Rate (kg/s)	Duration (s)	Time fraction	Safety system	Initial frequency	Frequen cy (y^-)
Instantaneous release	101 m^3	inst.	21%	-	5.0E-07 y^{-1}	1.0E-07
Continuous release from the largest connection (diameter 3 inch)	78 kg/s	644 s	21%	-	5.0E-07 y^{-1}	1.0E-07
Rupture arm (3 inch) (safety system operates)	21 kg/s	120 s	910 h	1	3.0E-08 h^{-1}	2.7E-05
Rupture arm (3 inch) (safety system fails)	21 kg/s	1800 s	910 h	1E-4	3.0E-08 h^{-1}	2.7E-09
Leak of the (un)loading arm (10% of the diameter)	0.8 kg/s	1800 s	910 h	-	3.0E-07 h^{-1}	2.7E-04
BLEVE	101 m^3	-	910 h	-	5.8E-10 h^{-1}	5.3E-07

Remarks

- The volume is 119 m^3. The filling rate is 85%.
- The diameter is 3 inch.
- Time fraction:
  - The presence of the road tanker on the site is 2 hour. There are 900 deliveries, so the time fraction is 21% (presence of the road tanker).
  - The flow rate is 100 m^3/h. Based on a volume of 101 m^3 the unloading duration is 1.01 hours. There are 900 deliveries, so the time fraction is 910 hours per year (unloading activity).
- The flow rate of the unloading activity is 100 m^3/hour. For the rupture of the unloading arm the outflow is 150% of the mean flow rate (according to the Dutch guidelines). This results in a flow rate of 21 kg/s propane.
- Safety system: see paragraph 2.3.
- BLEVE: the burst pressure of the BLEVE of the rail tankcar is 19.5 bar (gauge).

3.7 Road tanker loading station

Loading road tanker propane (21 m^3)

Scenarios for road tanker	Rate (kg/s)	Duration (s)	Time fraction	Safety system	Initial frequency	Frequency (y^{-1})
Instantaneous release	18 m^3	inst.	10 %	-	5.0E-07 y^{-1}	5.2E-08
Continuous release from the largest connection (diameter 3 inch)	78 kg/s	114 s	10 %	-	5.0E-07 y^{-1}	5.2E-08
Rupture arm (3 inch) (safety system operates)	13 kg/s	120 s	917 h	1	3.0E-08 h^{-1}	2.8E-05
Rupture arm (3 inch) (safety system fails)	13 kg/s	700 s	917 h	1E-4	3.0E-08 h^{-1}	2.8E-09
Leak of the (un)loading arm (10% of the diameter)	0,8 kg/s	1800 s	917 h	-	3.0E-07 h^{-1}	2.8E-04
BLEVE	18 m^3	-	917 h	-	5.8E-10 h^{-1}	5.3E-07

Remarks

- The volume is 21 m^3. The filling rate is 85%.
- The diameter is 3 inch.
- Time fraction:
  - The presence of the road tanker on the site is 20 minutes. There are 2750 deliveries, so the time fraction is 10% (presence of the road tanker).
  - The loading duration is 20 minutes. There are 2750 deliveries, so the time fraction is 917 hours per year (loading activity).
- The flow rate of the unloading activity is 60 m^3/hour. For the rupture of the unloading arm the outflow is 150% of the mean flow rate (according to the Dutch guidelines). This results in a flow rate of 13 kg/s propane.
- Safety system: see paragraph 2.3.
- BLEVE: the burst pressure of the BLEVE is 23.5 bar (gauge).

Loading road tanker propane (47 m^3)

Scenarios for road tanker	Rate (kg/s)	Duration (s)	Time fraction	Safety system	Initial frequency	Frequency (y^{-})
Instantaneous release	40 m^3	inst.	0.2 %	-	5.0E-07 y^{-1}	8.6E-10
Continuous release from the largest connection (diameter 3 inch)	78 kg/s	255	0.2 %	-	5.0E-07 y^{-1}	8.6E-10
Rupture arm (3 inch) (safety system operates)	13 kg/s	120 s	10 h	1	3.0E-08 h^{-1}	3.0E-07
Rupture arm (3 inch) (safety system fails)	13 kg/s	1800 s	10 h	1E-4	3.0E-08 h^{-1}	3.0E-11
Leak of the (un)loading arm (10% of the diameter)	0.8 kg/s	1800 s	10 h	-	3.0E-07 h^{-1}	3.0E-06
BLEVE	40 m^3	-	10 h	-	5.8E-10 h^{-1}	5.8E-09

Remarks

- The volume is 47 m^3. The filling rate is 85%.
- The diameter is 3 inch.
- Time fraction:
  - The presence of the road tanker on the site is 1 hour. There are 15 deliveries, so the time fraction is 1.5% (presence of the road tanker).
  - The flow rate is 60 m^3/h. Based on a volume of 40 m^3 the unloading duration is 40 minutes. There are 15 deliveries, so the time fraction is 10 hours per year (unloading activity).
- The flow rate of the unloading activity is 60 m^3/hour. For the rupture of the unloading arm the outflow is 150% of the mean flow rate (according to the Dutch guidelines). This results in a flow rate of 13 kg/s propane.
- Safety system: see paragraph 2.3.
- BLEVE: the burst pressure of the BLEVE is 23.5 bar (gauge).

Loading road tanker butane (21 m^3)

Scenarios for road tanker	Rate (kg/s)	Duration (s)	Time fraction	Safety system	Initial frequency	Frequency (y^-)
Instantaneous release	18 m^3	inst.	0.1 %	-	5.0E-07 y^{-1}	6.7E-10
Continuous release from the largest connection (diameter 3 inch)	34 kg/s	307	0.1 %	-	5.0E-07 y^{-1}	6.7E-10
Rupture arm (3 inch) (safety system operates)	15 kg/s	120 s	12 h	1	3.0E-08 h^{-1}	3.5E-07
Rupture arm (3 inch) (safety system fails)	15 kg/s	700 s	12 h	1E-4	3.0E-08 h^{-1}	3.5E-11
Leak of the (un)loading arm (10% of the diameter)	0,3 kg/s	1800 s	12 h	-	3.0E-07 h^{-1}	3.5E-06
BLEVE	18 m^3	-	12 h	-	5.8E-10 h^{-1}	6.8E-09

Remarks
- The volume is 21 m^3. The filling rate is 85%.
- The diameter is 3 inch.
- Time fraction:
  - The presence of the road tanker on the site is 20 minutes. There are 35 deliveries, so the time fraction is 0.1% (presence of the road tanker).
  - The loading duration is 20 minutes. There are 35 deliveries, so the time fraction is 12 hours per year (loading activity).
- The flow rate of the unloading activity is 60 m^3/hour. For the rupture of the unloading arm the outflow is 150% of the mean flow rate (according to the Dutch guidelines). This results in a flow rate of 15 kg/s butane.
- Safety system: see paragraph 2.3.
- BLEVE: the burst pressure of the BLEVE is 23.5 bar (gauge).

3.8 Lines unloading station

Line rail tankcar - vessel
The length of the unloading line from the rail tankcar to the vessel is 305 m. The average diameter is 7 inch.

Scenario for lines	Rate (kg/s)	Duration (s)	Time fraction	Length (m)	Safety system	Initial frequency $(m^{-}y^{-})$	Frequency (y^{-})
Rupture at 5 m	153	120+25	10%	20	1	1.0E-07	2.1E-07
	153	1800	10%	20	1E-4	1.0E-07	2.1E-11
Rupture at 30 m	122	120+31	10%	30	1	1.0E-07	3.1E-07
	122	1800	10%	30	1E-4	1.0E-07	3.1E-11
Rupture at 70 m	98	120+38	10%	50	1	1.0E-07	5.2E-07
	98	1800	10%	50	1E-4	1.0E-07	5.2E-11
Rupture at 130 m	81	120+47	10%	100	1	1.0E-07	1.0E-06
	81	1800	10%	100	1E-4	1.0E-07	1.0E-11
Rupture at 240 m	65	120+59	10%	105	1	1.0E-07	1.1E-06
	65	1800	10%	105	1E-4	1.0E-07	1.1E-11
Leak (10%D)	4.3	1800	10%	305	-	5.0E-07	1.6E-05

Remarks

- In accordance with the new guideline for QRA (at this moment RIVM elaborates an update of CPR 18) the rupture of a 307 metre line should be modeled at a length of 5 m (for 0-20 m), 30 m (for 20-50 m), 70 m (for 50-100 m), 130 (for 100-200 m) and 240 m (for 200-305 m).
- When the safety systems react the closing time is 120 s. But we also considered the amount of the line blocked. The amount is 3800 kg. This makes the duration longer.
- Time fraction: There are 900 deliveries of 101 m^3 rail tankcar per year. The flow rate is 100 m^3/h. This means a time fraction of 10%.
- Safety system: see paragraph 2.3.

<u>Line road tanker - vessel</u>

The length of the unloading line from the road tanker to the vessel is 258 m. The average diameter is 7 inch.

Scenario for lines	Rate (kg/s)	Duration (s)	Time fraction	Length (m)	Safety system	Initial frequency (m-y-)	Frequency (y-)
Rupture at 5 m	153	120+21	1%	20	1	1.0E-07	2.3E-08
	153	1800	1%	20	1E-4	1.0E-07	2.3E-12
Rupture at 30 m	122	120+26	1%	30	1	1.0E-07	3.4E-08
	122	1800	1%	30	1E-4	1.0E-07	3.4E-12
Rupture at 70 m	98	120+33	1%	50	1	1.0E-07	5.7E-08
	98	1800	1%	50	1E-4	1.0E-07	5.7E-12
Rupture at 130 m	81	120+40	1%	100	1	1.0E-07	1.1E-07
	81	1800	1%	100	1E-4	1.0E-07	1.1E-11
Rupture at 240 m	65	120+50	1%	58	1	1.0E-07	6.6-08
	65	1800	1%	58	1E-4	1.0E-07	6.6E-12
Leak (10%D)	4.3	1800	1%	258	-	5.0E-07	1.5E-06

Remarks

- In accordance with the new guideline for QRA (at this moment RIVM elaborates an update of CPR 18) the rupture of a 258 metre line should be modeled at a length of 5 m (for 0-20 m), 30 m (for 20-50 m), 70 m (for 50-100 m), 130 (for 100-200 m) and 240 m (for 200-258 m).
- When the safety systems react the closing time is 120 s. But we also considered the amount of the line blocked. The amount is 3200 kg. This makes the duration longer.
- Time fraction: There are 135 deliveries of 47 m^3 road tankers propane and 15 deliveries road tankers butane (47 m^3) per year. The flow rate is 60 m^3/h. This means a time fraction of 1%.
- Safety system: see paragraph 2.3.

3.9 Line loading station

The line form the vessel to the loading station (road tanker) is divided in two parts: the line from the vessel to the pump (length 55 m, diameter 10 inch) and the line from the pump to the loading station (length 200 m, diameter 6 inch).

Line vessel to pump

Scenario for lines	Rate (kg/s)	Duration (s)	Time fraction	Length (m)	Safety system	Initial frequency (m-y-)	Frequency (y-)
Rupture at 5 m	313	120+4	11%	20	1	1.0E-07	2.1E-07
	313	1800	11%	20	1E-4	1.0E-07	2.1E-11
Rupture at 30 m	271	120+5	11%	35	1	1.0E-07	3.8E-07
	271	1800	11%	35	1E-4	1.0E-07	3.8E-11
Leak (10%D)	8.7	1800	11%	55	-	5.0E-07	3.0E-06

Remarks

- In accordance with the new guideline for QRA (at this moment RIVM elaborates an update of CPR 18) the rupture of a 258 metre line should be modeled at a length of 5 m (for 0-20 m) and 30 m (for 20-55 m).
- When the safety systems react the closing time is 120 s. But we also considered the amount of the line blocked. The amount is 1400 kg. This makes the duration longer.
- Time fraction: the time fraction of 11 % has been based on all the loading activities together (2750 + 15 deliveries of propane and 35 deliveries of butane).
- Safety system: see paragraph 2.3.

Line pump to loading station

Scenario for lines	Rate (kg/s)	Duration (s)	Time fraction	Length (m)	Safety system	Initial frequency (m-y-)	Frequency (y-)
Rupture at 5 m	113	120+16	11%	20	1	1.0E-07	2.1E-07
	113	1800	11%	20	1E-4	1.0E-07	2.1E-11
Rupture at 30 m	86	120+21	11%	30	1	1.0E-07	3.2E-07
	86	1800	11%	30	1E-4	1.0E-07	3.2E-11
Rupture at 70 m	68	120+26	11%	50	1	1.0E-07	5.4E-07
	68	1800	11%	50	1E-4	1.0E-07	5.4E-11
Rupture at 130 m	56	120+32	11%	100	1	1.0E-07	1.1E-06
	56	1800	11%	100	1E-4	1.0E-07	1.1E-10
Leak (10%D)	3	1800	11%	200	-	5.0E-07	1.1E-05

Remarks

- In accordance with the new guideline for QRA (at this moment RIVM elaborates an update of CPR 18) the rupture of a 258 metre line should be modeled at a length of 5 m (for 0-20 m) and 30 m (for 20-55 m).

- When the safety systems react the closing time is 120 s. But we also considered the amount of the line blocked. The amount is 1800 kg. This makes the duration longer.
- Time fraction: the time fraction of 11 % has been based on all the loading activities together (2750 + 15 deliveries of propane and 35 deliveries of butane.
- Safety system: see paragraph 2.3.

4. Modeling aspects

4.1 Assumptions

The most important assumptions used in the calculation are:

- Day-night distribution is not considered (population data).
- A roughness length of 300 mm has been used.
- Within a cell (1000 m x 1000 m) there is a uniform distribution of population.
- Scenarios with a failure frequency of 1.0E-9 per year or smaller have been ignored.
- Head of vessel and road tanker:
    - The head of a vessel is 4 metre.
    - The head of the road tanker/rail tank car is 3 metre.
- Release direction and elevation:
    - The direction of a release is horizontal.
    - The elevation of a release is 1 metre.

4.2 Model

The calculations were done with SAFETI-NL v. 6.51.

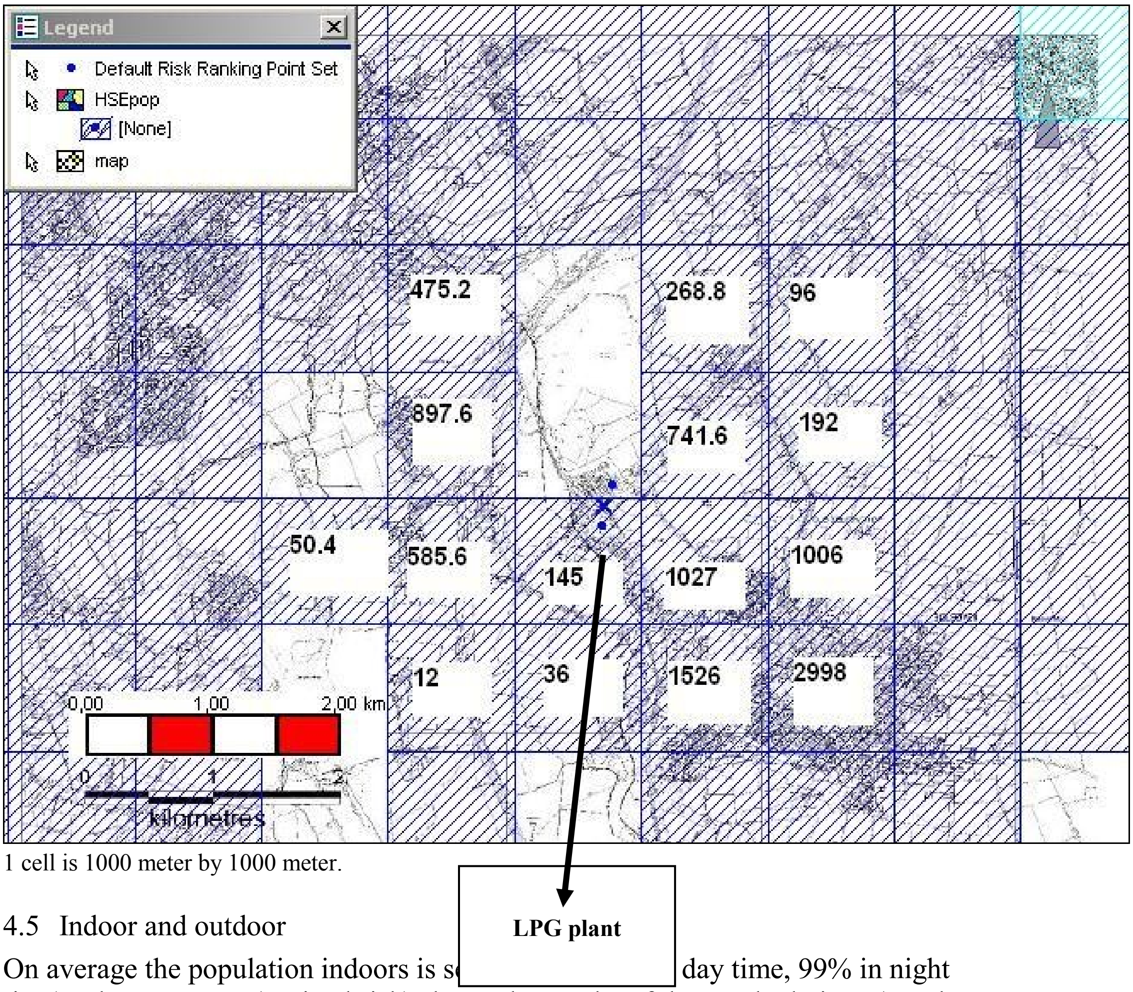
4.3 Conditions

The process conditions of propane and butane are saturated liquid with a temperature of 20 degrees Celsius.

4.4 Population data

The HSE delivered a population file of an area of 30 km x 30 km, with a grid size of 1000 m x 1000 m (per cell). This file has been transformed to an input file for SAFETI-NL. The figure shows the population in the vicinity of the plant. Within a cell there is a uniform distribution of population. The population has been considered as inhabitants of the communities in the neighborhood of the plant.

The OS coordinates of the plant are X = 445690, Y = 371790. Relative to the population data these are X = 14690, Y = 14790.



1 cell is 1000 meter by 1000 meter.

4.5 Indoor and outdoor

On average the population indoors is s day time, 99% in night time). The FN-curve (societal risk) shows the results of these calculations (see the definitions).

4.6 Weather data

The weather data of Watnall are the basis for the QRA. These data were also used for the Chlorine study and are from the HSE. Four meteorological classes are used.

Weather class	Probability
D2.4	0.15
D4.3	0.23
D6.7	0.45
F2.4	0.17

The distribution (in 12 sectors) of the wind direction per weather class is given in the next table. The table gives the sector **towards** the wind is going (and not from).

	345-15	15-45	45-75	75-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345
D 2.4	0,0879	0,1331	0,1279	0,0925	0,0767	0,0656	0,0761	0,0905	0,0774	0,0544	0,0538	0,0643
D 4.3	0,1002	0,1644	0,1497	0,092	0,0672	0,0581	0,0777	0,0881	0,0633	0,0399	0,0421	0,0573
D 6.7	0,123	0,1952	0,1565	0,0783	0,0487	0,0496	0,0805	0,0957	0,061	0,0309	0,0302	0,0503
F 2.4	0,0762	0,1619	0,1814	0,1312	0,094	0,0609	0,0668	0,0709	0,0479	0,0313	0,0337	0,0437

NB: The sector is the sector t**owards** the wind is blowing!

The combination of the probability of the weathers classes and the distribution per class is shown in the next table. The total of the probabilities is 1.

	345-15	15-45	45-75	75-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345
D 2.4	0,0132	0,0200	0,0192	0,0139	0,0115	0,0098	0,0114	0,0136	0,0116	0,0082	0,0081	0,0096
D 4.3	0,0230	0,0378	0,0344	0,0212	0,0155	0,0134	0,0179	0,0203	0,0146	0,0092	0,0097	0,0132
D 6.7	0,0554	0,0878	0,0704	0,0352	0,0219	0,0223	0,0362	0,0431	0,0275	0,0139	0,0136	0,0226
F 2.4	0,0130	0,0275	0,0308	0,0223	0,0160	0,0104	0,0114	0,0121	0,0081	0,0053	0,0057	0,0074

NB: The sector is the sector t**owards** the wind is blowing!

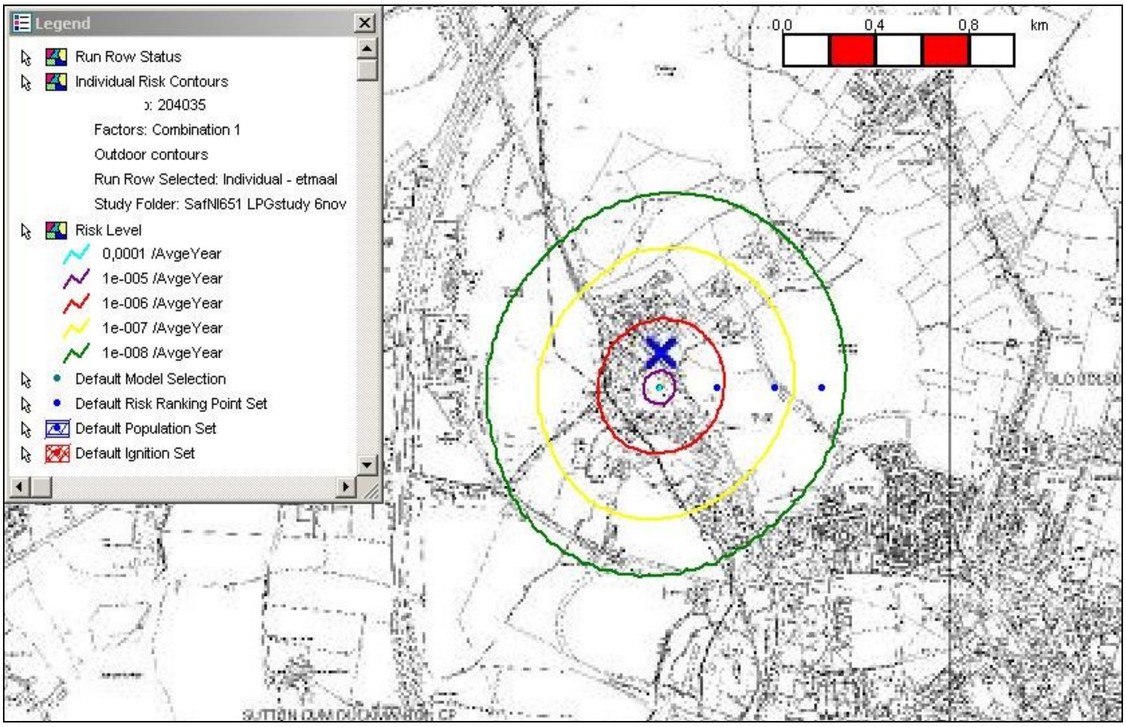
5. Results

The results of a QRA are the Location Based Risk (Individual Risk) and the Societal Risk:

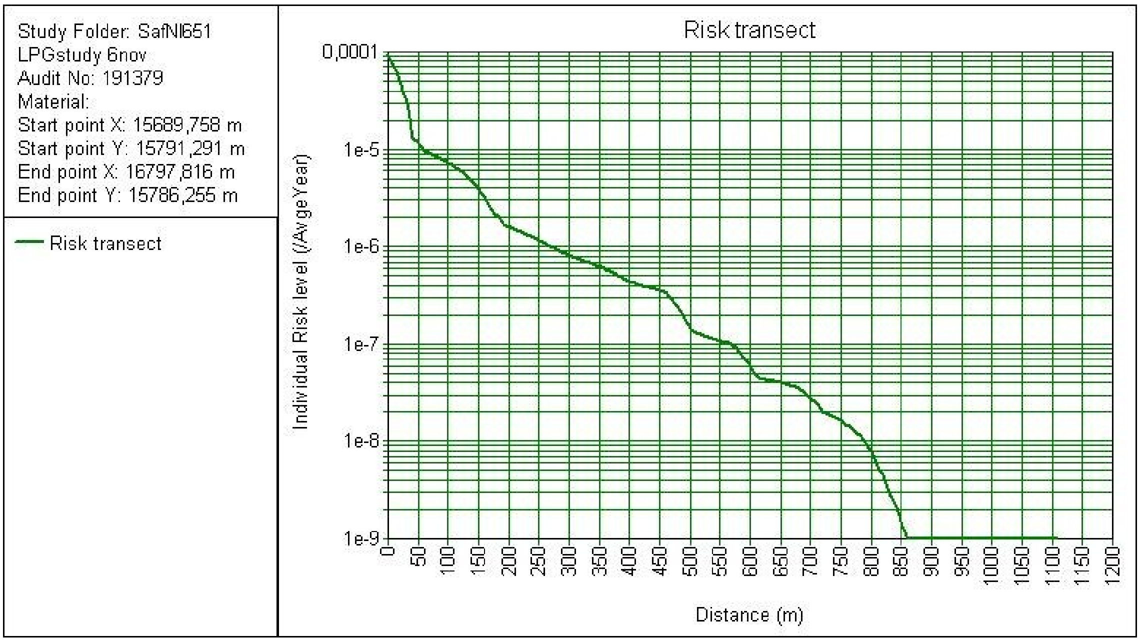
- The **Location based risk** represents the frequency of an individual dying due to loss of containment events. The individual is assumed to be unprotected and to be present during the total exposure time. The location based risk is presented as contour lines on a map. For the land use-planning the risk level 1.0E-6 per year contour is the limiting value (the standard) in the Netherlands.

- The **Societal Risk** represents the frequency of having an accident with N or more people be killed simultaneously. 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. To judge the societal risk an guide value is used.

5.1 Location based risk



The risk level of 1.0E-6 is the red contour on the map. Within this contour no vulnerable objects (houses) are allowed in the Netherlands. To see the distances to the contours we made a cross-section of the contours.



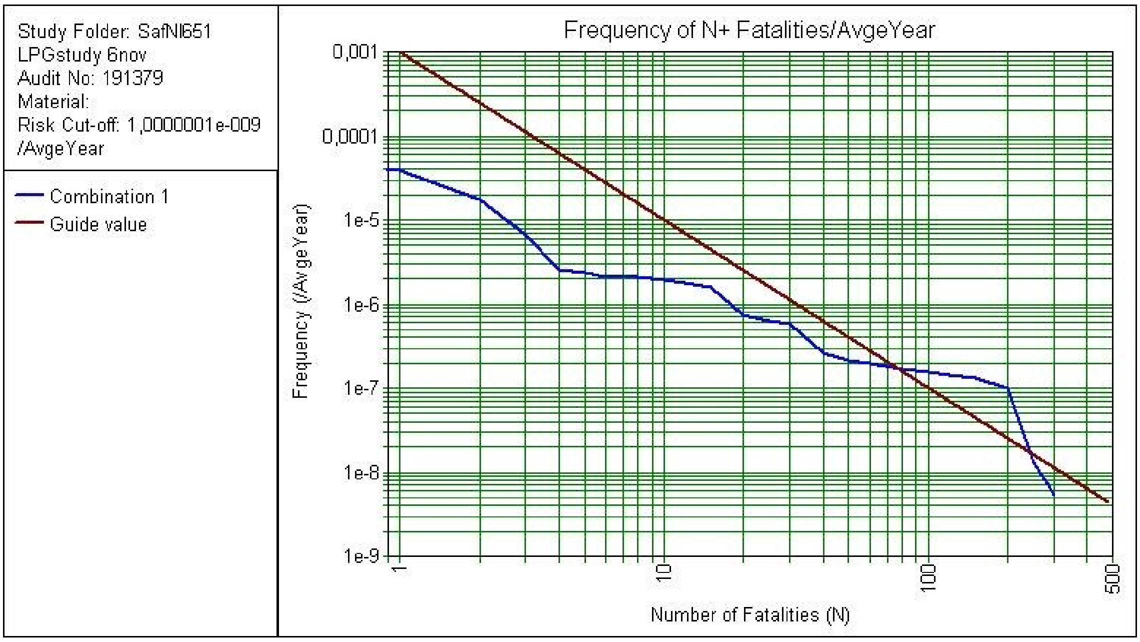
The distances are:

- 1.0E-5 per year contour: 50 m
- 1.0E-6 per year contour: 250 m
- 1.0E-7 per year contour: 550 m
- 1.0E-8 per year contour: 800 m

For analyzing the risks results a couple of risk ranking points have been laid down in the model. The first ranking point has been located at a distance of 250 m of the release point (origin); the second at a distance of 500 m and the last point at a distance of 700 m. The first risk ranking point (at 250 m) overlaps the 1.0E-6 per year contour (red contour). The next table shows the scenarios determining the location based risk at the risk ranking points (contribution of the scenario is more then 10 % at a risk ranking point).

Risk ranking point	Main scenarios
At 250 m of origin	Vessel butane - Instantaneous release Vessel propane- Continuous release of the complete inventory in 10 min Vessel propane - Instantaneous release Rail tank car propane (119m^3) - Bleve
At 500 m of origin	Vessel butane - Instantaneous release Vessel propane - Instantaneous release Vessel propane- Continuous release of the complete inventory in 10 min
At 700 m of origin	Vessel butane - Instantaneous release

5.2 Societal risk



The calculated societal risk exceeds the "acceptable" FN curve (guide value).

The societal risk ranking report shows that the scenario ‘catastrophic failure’ of the pump propane while the safety system operates contributes greatly to the societal risk of a small number of fatalities (1-10). The scenarios ‘instantaneous release’ of the storage vessel propane and the vessel butane determine the societal risk of a large number of fatalities (>100).

Annex 5. FPMs report LPG comparison study

FPMs, report of December 8, 2008

Benchmark study of a LPG depot

Quantification of the external risk according to the methodology used in Walloon Region (Belgium) for land use planning purposes

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Contents

1. Introduction

Decision-making regarding land use planning around Seveso plants requires the quantification of the external risk due to the plant. The method for the quantification of the external risk varies between European countries, and the criteria for the acceptability of the external risk vary also.

The objectives of this "benchmark project" is to analyse a fictitious LPG plant according to the methods and criteria used in France (INERIS), the United Kingdom (HSE), the Netherlands (RIVM) and in Belgium – Walloon region (FPMs).

A common LPG plant is described and common assumptions are made [Ineris 2007].

Each partner has then to quantify the external risk according to the method used in his country, and also to identify the land use possibilities according to the criteria used in the decision making phase.

The present report describes the approach used in Belgium (Walloon region). Paragraph 2 summarizes the main points related to the land use planning methodology used in Walloon Region. Paragraph 3 proposes a brief description of the LPG plant, subject of this benchmark exercise. Paragraph 4 explains the methodology used for the quantification of the external risk of the LPG plant, while paragraph 5 shows the results of this quantification. The sensibility of the results is discussed in paragraph 6.

2. Land use planning around major hazard plants in Walloon Region (Belgium)

2.1. Parties involved

In Belgium, land use planning falls within the competence of regional authorities. This means that each region (Wallonia, Flanders and Brussels) has developed its own methodology and regulations. Since 2003, the Ministry of Walloon Region has worked in this field in collaboration with the "Major Risk Research Centre" of the "Faculté Polytechnique de Mons" in order to develop a consistent and transparent methodology to assure a sustainable land use planning around Seveso plants.

Two parts can be distinguished in the land use planning issue, and two parties are involved in. The first one is the risk assessment leading to the definition of risk curves around the plants. The second part is the "political" management of these curves, or the decision-making process.

In practical terms, Walloon Authorities decided to introduce the concept of "consultation zones" around each Seveso plant. A consultation zone is defined as a zone in which a major accident could induce harmful effects for people or infrastructure, with a non negligible frequency of occurrence. These consultation zones are made available for planning authorities. When a new development (house, public infrastructure, etc) is planned and a building licence is requested, planners have to verify if the project is located in a consultation zone. If yes, they need to obtain a favourable recommendation from the regional Seveso Competent Authority before granting the licence.

These consultations zones have to be defined in a consistent way, and thus the support of an external scientific expert has been searched. The "Major Risk Research Centre" of the "Faculté Polytechnique de Mons" (FPMs) plays this role and calculates risk curves around the Seveso plant. The recourse to an only expert to perform the risk calculation offers the advantage of a common methodology and common assumptions for every Seveso plant in the Region. With the risk curves obtained, the Walloon Region draws the consultation zones on the local maps.

2.2. Summary of the methodology of quantification of the external risk used in Walloon Region

In Walloon Region, the approach selected for the risk assessment and the determination of the consultation zones is similar to a full probabilistic approach, which is called a "QRA" (Quantitative Risk Assessment). However, the approach chosen differs from a classic QRA method on several points, the most important one being that the risk is not expressed in terms of fatalities but is linked with the possibility of irreversible damage for people.

The main steps used for the quantification of the external risk are shown in Figure A5-1.

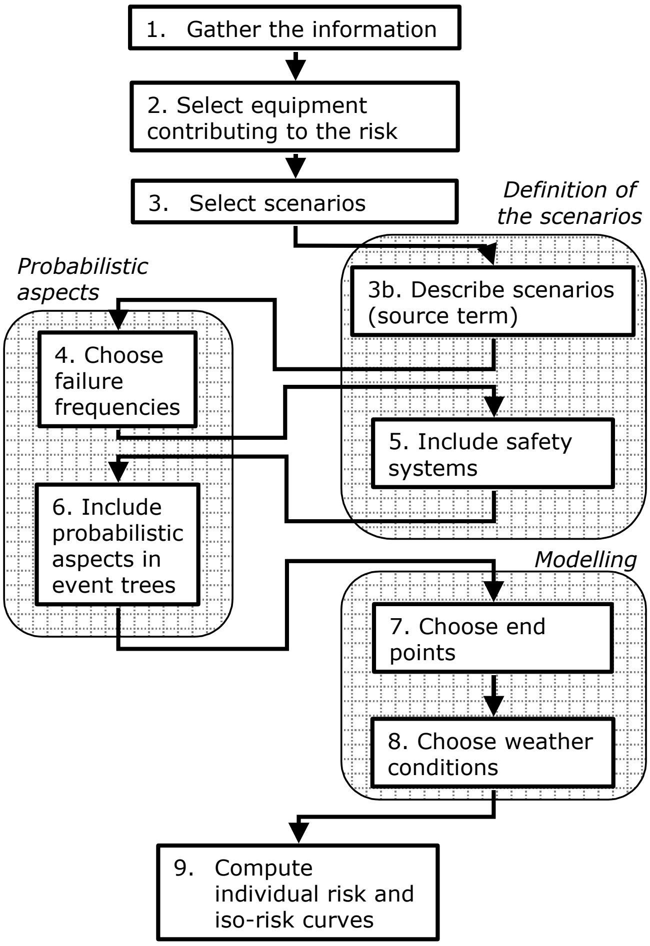

Figure A5-1 Main steps for the quantification of the external risk

The quantification of the external risk begins with the gathering of information concerning the Seveso plant. Main inputs are the equipment, the hazardous substances, the process data, etc.

The equipment which have to be included in the risk assessment are selected during the second step. The selection is based on a comparison of the quantity of hazardous substance contained in the equipment with thresholds values [Ministry of Walloon Region 2005].

During the third step, accident scenarios are associated with every selected piece of equipment. This is done in a very systematic way, with typical scenarios always selected according to the type of piece of equipment. For example, for transport equipment, a catastrophic rupture and two breaches (diameter 100 and 35 mm) are studied for the rail/road tank car, together with the full bore rupture of the unloading hose, and also the rupture and a breach of 25 mm diameter on the unloading pump.

For each scenario, a failure frequency must be chosen. The methodology uses generic frequencies, which means that the analysis of the causes of the scenario is not performed. The frequency is directly obtained for the loss of containment event (for example, a breach on a vessel or on a pipe). Generic frequencies are the same than those used in the Flemish Region, in Belgium [Aminal 2004].

As a fifth step, the influence of safety systems is taken into account. Safety systems acting upstream from the loss of containment event (preventive safety systems) are hardly included in this methodology, because generic frequencies are used for the scenarios (loss of containment). Downstream of the loss of containment, safety systems are modelled by the introduction of a double scenario. The first one has a high frequency, and limited consequences because of the successful intervention of the safety system. The second one has a lower frequency but is characterized by the failure of the safety system and thus is linked to important consequences.

In order to close the probabilistic part of the study, it is then necessary to choose values for probabilistic parameters appearing in the event tree, as ignition probabilities and probabilities of failure on demand of safety systems.

At the end of the process, the deterministic modelling of the consequences of the accident scenarios is performed with the help of the software PHAST RISK 6.53.1 (formerly SAFETI), which delivers iso-risk curves as final result. End point values are related to the risk of irreversible damage. The end points selected are: ERPG3 for toxic effects, 50 mbar for overpressure effects, and 6.4 kW/m² for thermal radiation.

Weather parameters necessary for the computation of the effect distances are site-specific and are obtained from records of the nearest weather station.

More detailed information on the methodology of quantification of the external risk used in Walloon Region can be found in previous publications [Delvosalle et al. 2006].

2.3. Short overview of the decision-making process in Walloon Region

For each Seveso plant (upper and lower tier), the external risk is quantified by the FPMs, which delivers results in the form of iso-risk curves on the map of the plant and its surroundings. The area delimited by the 10^{-6} per year iso-risk curve is called the "consultation zone", inside which the advice from the competent authority must be taken for every project concerning land use.

The maps are used by the competent authorities to issue building permits in the surroundings of the plant, so that neighbouring people are not exposed to an unacceptable risk. Authorities base their decision on a matrix adopted by the regional government, crossing the level of individual risk and the type of project for which the permit is applied for (industry, residential area, hospital, etc). In particular, it is interesting to note that houses are allowed on spots exposed to a risk inferior to 10^{-5} per year, while vulnerable buildings like hospitals and day nurseries are allowed if the risk is inferior to 10^{-6} per year.

This matrix is presented in Table A5-1. It must be reminded that the individual risk expressed here is not a risk of fatality but a risk of irreversible damage. The societal risk is not taken into account.

Table A5-1 Matrix for the decision-making process inside the consultation zone

	Individual risk		
	10^{-3} to 10^{-4} per year	**10^{-4} to 10^{-5} per year**	**10^{-5} to 10^{-6} per year**
Type A: Buildings and technical units directly linked with the geography *(catchment, water tower, wastewater treatment, windmill, etc)*	**OK**	**OK**	**OK**
Type B: Buildings for a few people, for the most part adult and autonomous *(workshop, logistic units, small shops, etc)*	With caution	**OK**	**OK**
Type C: Buildings for people, for the most part adult and autonomous, but without number restriction *(accommodation, workshops or offices for more than 100 people, schools and dormitories for students aged 12 and over, etc)*	Not allowed	With caution	**OK**
Type D: Buildings for susceptible people, with restricted autonomy *(hospitals, rest homes, schools and dormitories for children under 12, prisons, etc)*	Not allowed	Not allowed	With caution

3. Brief description of the plant

Based on the information received [Ineris 2007], a diagram of the equipment included in the study is proposed in Figure A5-2. The LPG depot is composed of 3 storage vessels, an unloading area and a loading station. It is supposed that all the equipment are located at the same point (case A) or are forming a line (case B). See paragraph 4.4 for the exact location of equipment.

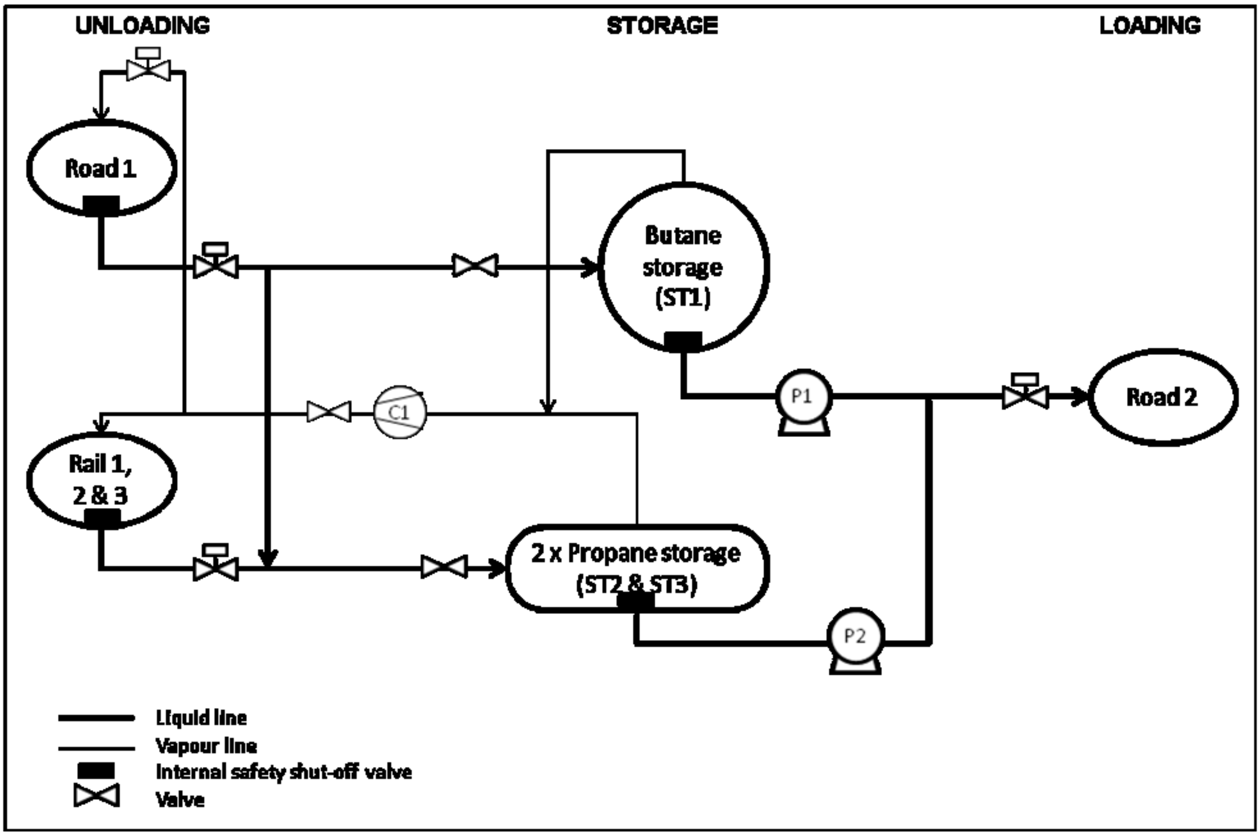

Figure A5-2 Main equipment in the LPG depot

The storage farm includes:

- Storage 1: spherical vessel (700 m³) for butane (ST1).
- Storage 2: mounded cylindrical vessel (2500 m³) for propane (ST2).
- Storage 3: identical to storage 2 (ST3).

The unloading facilities:

- 3 rail tank cars for the delivery of propane (Rail 1, Rail 2, Rail 3);
- 1 road tank car for the delivery of both propane and butane (Road 1).

The unloading is made thanks to a compressor (C1) on the vapour line. Two unloading arms are present for each tank car: one arm for the vapour phase and one arm for the liquid phase.

The loading facility:

- 1 road tank car able to load both propane and butane (Road 2).

The loading is made through pumps (P1 and P2) on the liquid line between the vessels and the road tank car.

More precision on the equipment (eg safety systems and operating conditions) will be given in the paragraphs describing the scenarios.

4. Quantification of the external risk for the LPG depot

4.1. Equipment selection

The method for the selection of equipment can be found in [Ministry of Walloon Region 2005]. The results are shown in Table A5-2.

Table A5-2 Equipment selection

Nr	Equipment	Substance	Selection
ST1	Spherical storage 700 m³	Butane	**Yes**
ST2 and ST3	2* cylindrical storage 2500 m³	Propane	**Yes**
Rail 1-2-3	Unloading rail tank car 119 m³	Propane	**Yes**
Road 1	Unloading road tank car 47 m³	Propane	**Yes**
	Unloading road tank car 47 m³	Butane	**Yes**
Road 2	Loading road tank car 21 m³	Propane	**Yes**
	Loading road tank car 47 m³	Propane	**Yes**
	Loading road tank car 21 m³	Butane	**Yes**
Pipe PRO1	Rail 1 → ST2 (liquid line)	Propane	**Yes**
Pipe BUT1	*Road 1 → ST1 (liquid line)*	*Butane*	*No*
Pipe PRO2	Road 1 → ST2 (liquid line)	Propane	**Yes**
Pipe BUT2	*ST1 → Road 2 (liquid line)*	*Butane*	*No*
Pipe PRO3	ST2 → Road 2 (liquid line)	Propane	**Yes**

It can be observed that all the equipment are selected except the lines carrying butane.

Vapour lines for the unloading, including the compressor, are not taken into account. Our experience shows that the contribution to the external risk is generally small. The liquid lines are predominant.

4.2. Scenarios

4.2.1. Spherical vessel (ST1)

Data:
- Substance: butane.
- Capacity 700 m³, maximum filling rate 55 % → 385 m³ available.
- Operating conditions: 20 °C, saturated liquid.
- Bund: surface 8 m * 8 m (= 64 m²), capacity 20 % of the vessel.

Scenarios:

Table A5-3 Scenarios for ST1

Scenario	Frequency (/y)	Comments
Catastrophic rupture	3 E-7	
Breach 100 mm on the vessel	3 E-6	
Breach 35 mm on the vessel	4.4 E-6	

4.2.2. Cylindrical vessel (ST2 and ST3)

Remark: as the vessels ST2 and ST3 are strictly identical, only one of them will be described here. Frequencies will be multiplied by 2.

Data:
- Substance: propane.
- Mounded storage.
- Capacity: 2500 m³, maximum filling rate 85 % → 2125 m³ available.
- Operating conditions: 20 °C, saturated liquid.

- Bund: no

Scenarios:

Table A5-4 Scenarios for ST2/ST3

Scenario	Frequency (/y)	Comments
Catastrophic rupture	2 E-7	= 1 E-7 * 2
Breach 100 mm on the vessel	6 E-6	= 3 E-6 * 2
Breach 35 mm on the vessel	8.8 E-6	= 4.4 E-6 * 2

Concerning the catastrophic rupture, the BLEVE is not considered. The effects will be modelled considering the release of the propane.

For the breaches, it has been decided to define the direction of the jet as "horizontal with impingement".

4.2.3. Unloading rail tank car (RAIL 1, 2 and 3)

Remark: 3 identical rail tank cars are used to deliver propane to the depot. Only one is described here. The frequency will include the number of deliveries per year. As this number is given for the 3 rail tank cars together, the frequencies do not need to be multiplied by 3.

Data:

- Substance: propane.
- Rail tank car.
- Capacity: 119 m³, filling rate 85 % → 101.15 m³ available.
- Operating conditions: 20°C, discharge due to compressor (ΔP = 1 bar) → $p = p_{sat}$ + 1 bar.
- 900 propane deliveries per year.
- Duration of 1 delivery: 2 hours (total time staying).
- Unloading flow rate: 100 m³/h.

Scenarios:

Table A5-5 Scenarios for RAIL1, 2, 3

Scenario	Frequency (/y)	Comments
Catastrophic rupture	6.16 E-8	= 3 E-7 * 900 * 2 / (24*365)
Breach 100 mm on the vessel	6.16 E-7	= 3 E-6 * 900 * 2 / (24*365)
Breach 35 mm on the vessel	9.04 E-7	= 4.4 E-6 * 900 * 2 / (24*365)

For all the scenarios, it is supposed that the operating pressure is equal to the pressure exerted by the compressor. Even if the compressor is stopped in case of release, the pressure is present and will only decrease with the flowing of propane outside the tank car.

4.2.4. Unloading road tank car (ROAD1)

Data:

- Substance: propane or butane.
- Road tank car.
- Capacity: 47 m³, filling rate 85 % → 39.95 m³ available.
- Operating conditions: 20°C, discharge due to compressor (ΔP = 1 bar).
- 135 propane and 15 butane deliveries per year.
- Duration of 1 delivery: 1 hour (total time staying).
- Unloading flow rate: 60 m³/h.

Scenarios:

Table A5-6 Scenarios for ROAD1

Scenario	Substance	Frequency (/y)	Comments
Catastrophic rupture	Propane	4.62 E-9	= 3 E-7 * 135 * 1 / (24*365)
Breach 100 mm on the vessel	**Propane**	**4.62 E-8**	= 3 E-6 * 135 * 1 / (24*365)
Breach 35 mm on the vessel	**Propane**	**6.78 E-8**	= 4.4 E-6 * 135 * 1 / (24*365)
Catastrophic rupture	Butane	5.14 E-10	= 3 E-7 * 15 * 1 / (24*365)
Breach 100 mm on the vessel	Butane	5.14 E-9	= 3 E-6 * 15 * 1 / (24*365)
Breach 35 mm on the vessel	Butane	7.53 E-9	= 4.4 E-6 * 15 * 1 / (24*365)

For all the scenarios, it is supposed that the operating pressure is equal to the pressure exerted by the compressor. Even if the compressor is stopped in case of release, the pressure is present and will only decrease with the flowing of propane outside the tank car.

Remark: only the scenarios whose frequency is higher than 1 E-8 per year are modelled. This means that 4 scenarios of Table A5-6 will no longer more be considered in the study: the catastrophic rupture of the propane tank car and all the scenarios of the butane tank car.

4.2.5. Loading road tank car (ROAD2)

Data:

- Substance: propane or butane.
- Road tank car.
- Capacity: 21 m³ in most cases, 47 m³ for 15 propane loading per year (see Table A5-7), filling rate 85 %.
- Operating conditions: 20°C, saturated liquid.
- Per year:
  - 2750 propane loading (21 m³);
  - 15 propane loading (47 m³);
  - 35 butane loading (21 m³).
- Duration of 1 delivery: 20 min (total time staying).
- Loading flow rate: 60 m³/h.

Scenarios:

Table A5-7 Scenarios for ROAD2

Scenario	Substance	Volume (m³)	Frequency (/y)	Comments
Catastrophic rupture	**Propane**	**21**	**3.14 E-8**	= 3 E-7 * 2750 * 1/3 / (24*365)
Breach 100 mm on the vessel	**Propane**	**21**	**3.14 E-7**	= 3 E-6 * 2750 * 1/3 / (24*365)
Breach 35 mm on the vessel	**Propane**	**21**	**4.6 E-7**	= 4.4 E-6 * 2750 * 1/3 / (24*365)
Catastrophic rupture	Propane	47	1.71 E-10	= 3 E-7 * 15 * 1/3 / (24*365)
Breach 100 mm on the vessel	Propane	47	1.71 E-9	= 3 E-6 * 15 * 1/3 / (24*365)
Breach 35 mm on the vessel	Propane	47	2.51 E-9	= 4.4 E-6 * 15 * 1/3 / (24*365)
Catastrophic rupture	Butane	21	4 E-10	= 3 E-7 * 35 * 1/3 / (24*365)
Breach 100 mm on the vessel	Butane	21	4 E-9	= 3 E-6 * 35 * 1/3 / (24*365)
Breach 35 mm on the vessel	Butane	21	5.86 E-9	= 4.4 E-6 * 35 * 1/3 / (24*365)

Remark: only the scenarios whose frequency is higher than 1 E-8 per year are modelled. This means that we will only consider the scenarios related to the 21 m³ propane tank car.

4.2.6. Liquid pipeline between Rail1 and ST2 (propane): PRO1

For convenience, pipes are divided in several parts indicated by start and end letters as shown in Figure A5-3.

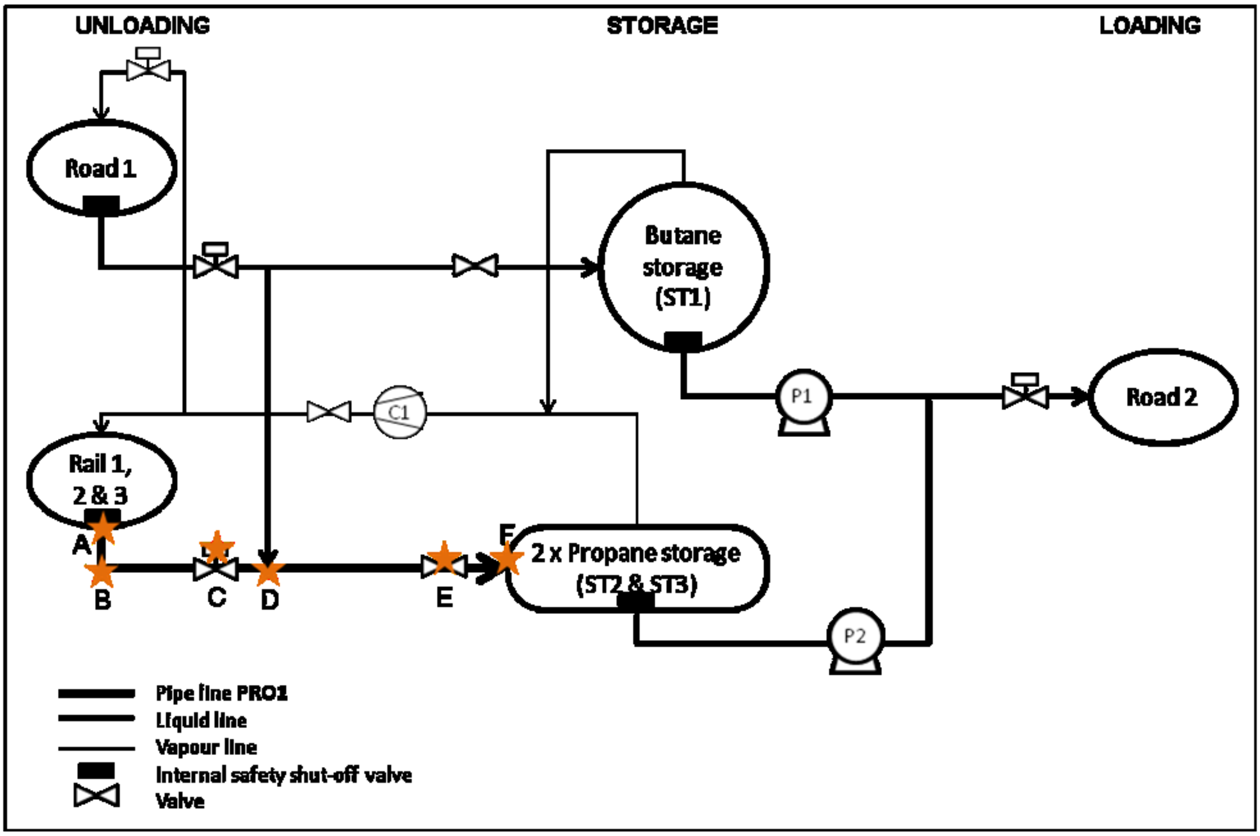

Figure A5-3 Letters to form several parts on pipe PRO1 (from RAIL1,2,3 to ST2/ST3)

Data:

- Pipe carrying propane.
- Dimensions as mentioned in Table A5-8.
- Operating conditions: 20°C, saturated liquid + 1 bar ∆P.
- Flow rate 100 m³/h.

Table A5-8 Dimensions for pipe PRO1

Part	Diameter (mm)	Length (m)	Volume (m³)
PRO1-AB	80	7	0.035
PRO1-BC	100	45	0.353
PRO1-CD	100	7	0.055
PRO1-DE	100	46	0.361
PRO1-EF			7.167
PRO1-EF1	200	150	4.712
PRO1-EF2	250	50	2.454

Other equipment:

- Unloading arm 3".

Safety systems:

- 1 safety shut off valve at the bottom of the rail tank car (point A on Figure A5-3);
- 1 safety valve (point C on Figure A5-3);
- 1 safety valve (point E on Figure A5-3);
- Safety valves are closed and the pumps and compressors stopped if:
  - there is a gas detection;
  - or an operator presses on an emergency button.

Even if it is not précised in the plant description, we suppose that there is a physical system to avoid the emptying of the downstream vessel (cylindrical storage).

Scenarios without safety systems

The pipeline must be divided in several parts in order to choose release points. These points must be chosen every 100 m in general, and depend on the position of safety valves. Basic scenarios are shown in Table A5-9, without the influence of safety systems in a first step. The calculated frequencies depend on the pipe diameter and length, and also on the number of hours during which the pipe is used.

Table A5-9 Scenarios for PRO1 (without safety systems)

Part	Scenario	Quantity between 2 safety valves (kg)	Frequency (/y)	Distance between the upstream vessel (Rail1) and the release location (m)
Arm1 (Propane)	Full bore rupture	194	5.4 E-5	2
PRO1-AC (Propane)	Full bore rupture	194	2.43 E-6	26
	Breach 44 %		5.52 E-6	
	Breach 22 %		1.33 E-5	
PRO1-CE (Propane)	Full bore rupture	208	2.4 E-6	78.5
	Breach 44 %		5.45 E-6	
	Breach 22 %		1.31 E-5	
PRO1-EF (Propane)	Full bore rupture	3576	4.29 E-6	205
	Breach 44 %		9.76 E-6	
	Breach 22 %		2.34 E-5	

Scenarios with safety systems

The following assumptions are made for the influence of the safety systems:

- (Safety system 1) The gas detection will close the valve in 2 minutes, with a probability of failure equal to 0.01.
- (Safety system 2) In case of failure of this first safety system, an operator can push on an emergency button, with a time reaction of 10 minutes and the closing of another valve (the first safety system could fail due to the non closing of a valve). Probability of failure of this second safety system: 0.01.

Details about involved safety systems and resulting scenarios are shown in Figure A5-4 and Table A5-10.

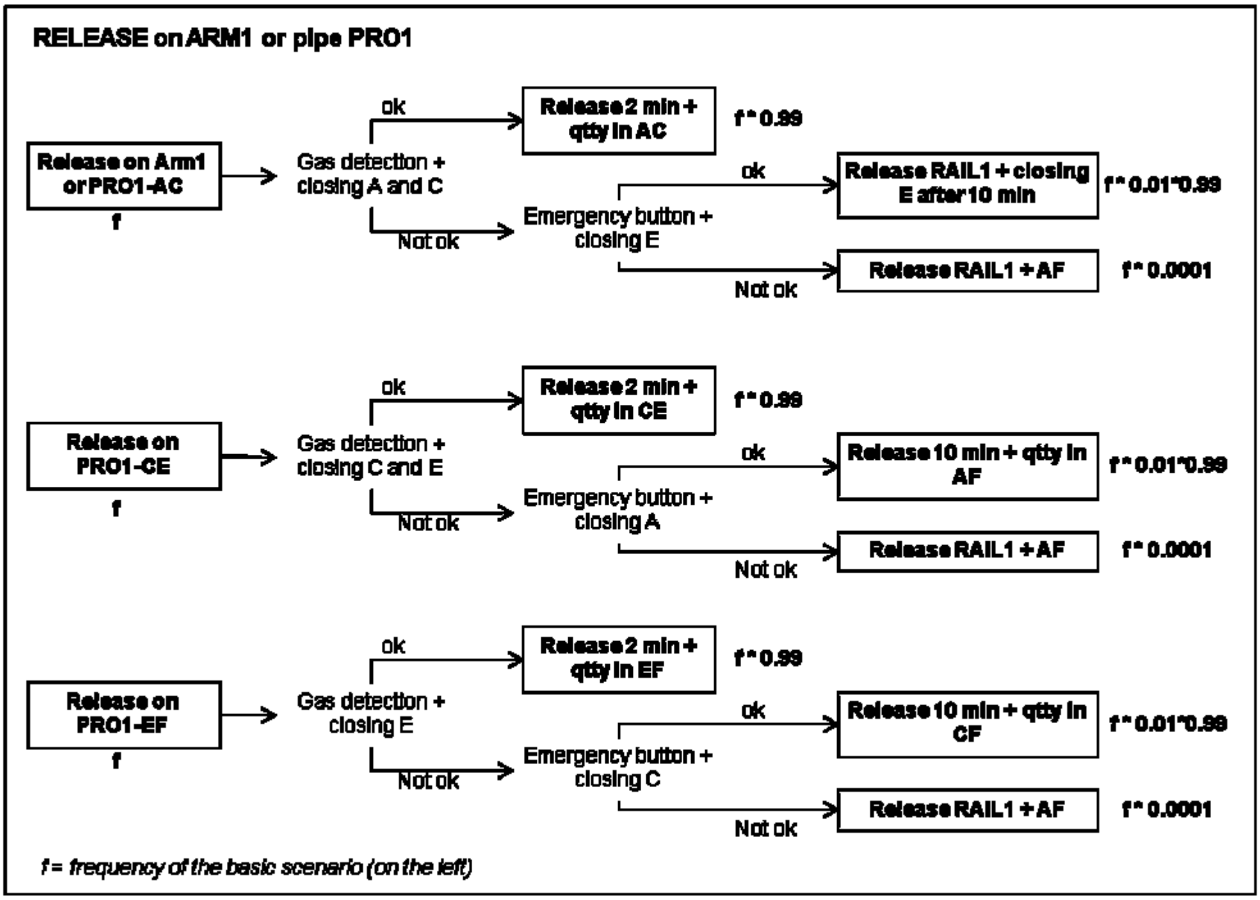

Figure A5-4 Influence on safety systems on scenarios on ARM1 and pipe PRO1

Table A5-10 Scenarios for PRO1 (with safety systems)

Part	Scenario (SSi = successful action of safety system i)	Frequency (/y)	Release conditions	Release location (m)
Arm1 (Propane)	Full bore rupture SS1	5.35 E-5	Release during 2 min + quantity in AC	2
	Full bore rupture SS2	5.35 E-7	Release of the quantity in RAIL1 + closing E after 10 min	
PRO1-AC (Propane)	Full bore rupture SS1	2.41 E-6	Release during 2 min + quantity in AC	26
	Full bore rupture SS2	2.41 E-8	Release of the quantity in RAIL1 + closing E after 10 min	
	Breach 44 % SS1	5.47 E-6	Release during 2 min + quantity in AC	
	Breach 44 % SS2	5.47 E-8	Release of the quantity in RAIL1 + closing E after 10 min	
	Breach 22 % SS1	1.31 E-5	Release during 2 min + quantity in AC	
	Breach 22 % SS2	1.31 E-7	Release of the quantity in RAIL1 + closing E after 10 min	
PRO1-CE (Propane)	Full bore rupture SS1	2.37 E-6	Release during 2 min + quantity in CE	78.5
	Full bore rupture SS2	2.37 E-8	Release during 10 min + quantity in AF	
	Breach 44 % SS1	5.39 E-6	Release during 2 min + quantity in CE	
	Breach 44 % SS2	5.39 E-8	Release during 10 min + quantity in AF	
	Breach 22 % SS1	1.29 E-5	Release during 2 min + quantity in CE	
	Breach 22 % SS2	1.29 E-7	Release during 10 min + quantity in AF	
PRO1-EF (Propane)	Full bore rupture SS1	4.25 E-6	Release during 2 min + quantity in EF	205
	Full bore rupture SS2	4.25 E-8	Release during 10 min + quantity in CF	
	Breach 44 % SS1	9.66 E-6	Release during 2 min + quantity in EF	
	Breach 44 % SS2	9.66 E-8	Release during 10 min + quantity in CF	
	Breach 22 % SS1	2.32 E-5	Release during 2 min + quantity in EF	
	Breach 22 % SS2	2.32 E-7	Release during 10 min + quantity in CF	

Remark: in Table A5-10, scenarios whose frequency should be multiplied by 0.0001 are not taken into account because their final frequency should be lower than 1 E-8 and thus they will not be considered for the modelling.

4.2.7. Liquid pipeline between ROAD1 and ST2 (propane): PRO2

For convenience, pipes are divided in several parts indicated by start and end letters as shown in Figure A5-5.

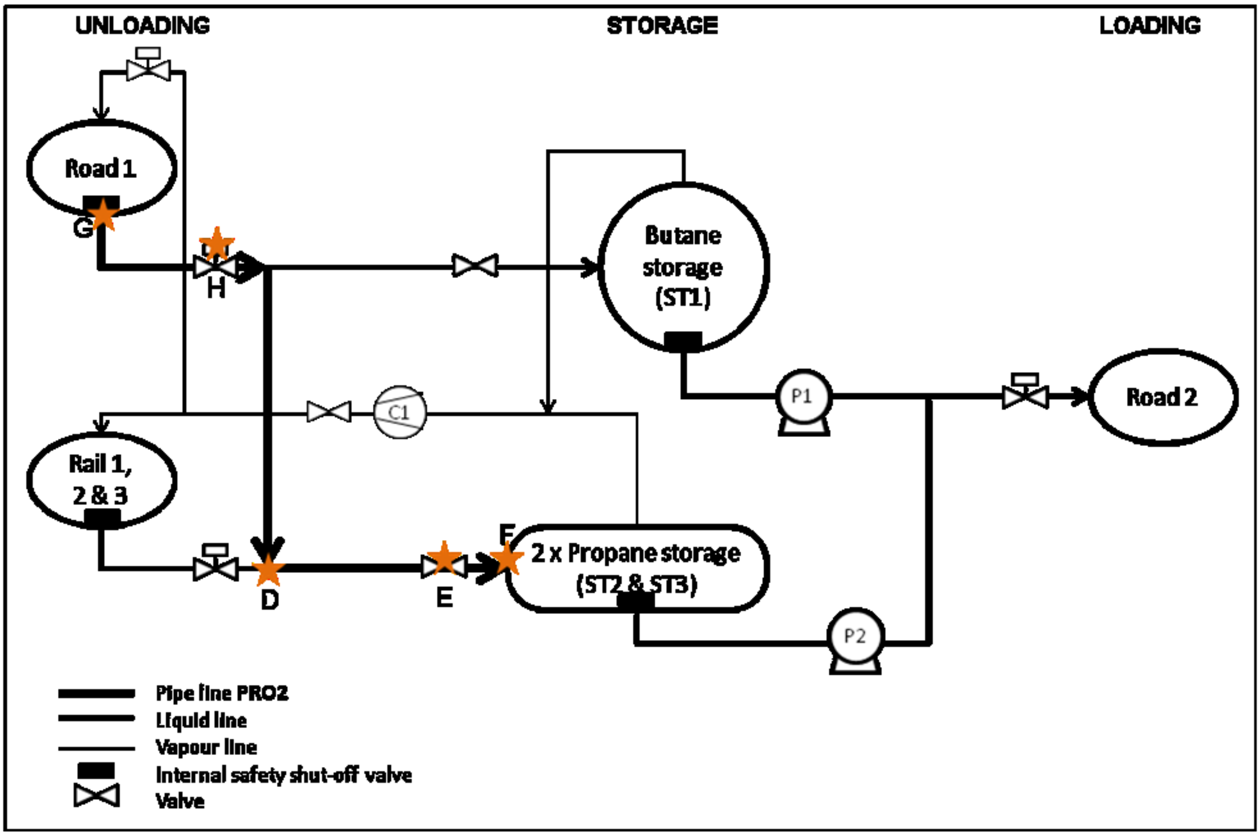

Figure A5-5 Letters to form several parts on pipe PRO2 (from ROAD1 to ST2/ST3)

Data:

- Pipe carrying propane.
- Dimensions as mentioned in Table A5-11.
- Operating conditions: 20°C, saturated liquid + 1 bar ΔP.
- Flow rate 60 m³/h.

Table A5-11 Dimensions for pipe PRO2

Part	Diameter (mm)	Length (m)	Volume (m³)
PRO2-GH	80	10	0.050
PRO2-HD	100	2	0.016
PRO2-DE	100	46	0.361
PRO2-EF			7.167
PRO2-EF1	200	150	4.712
PRO2-EF2	250	50	2.454

Other equipment:

- Unloading arm 3".

Safety systems:

- 1 safety shut off valve at the bottom of the road tank car (point G on Figure A5-5).
- 1 safety valve (point H on Figure A5-5).
- 1 safety valve (point E on Figure A5-5).

- Safety valves are closed and the pumps and compressors stopped if:
    - there is a gas detection;
    - or an operator presses on an emergency button.

Even if it is not précised in the plant description, we suppose that there is a physical system to avoid the emptying of the downstream vessel (cylindrical storage).

Scenarios without safety systems

The pipeline must be divided in several parts in order to choose release points. These points must be chosen every 100 m in general, and depend on the position of safety valves. Basic scenarios are shown in Table A5-12, without the influence of safety systems in a first step. The calculated frequencies depend on the pipe diameter and length, and also on the number of hours during which the pipe is used.

Table A5-12 Scenarios for PRO2 (without safety systems)

Part	Scenario	Quantity between 2 safety valves (kg)	Frequency (/y)	Distance between the upstream vessel (Rail1) and the release location (m)
Arm2 (Propane)	Full bore rupture	25	4.05 E-6	2
PRO2-GH (Propane)	Full bore rupture	25	4.24 E-8	5
	Breach 44 %		9.63E-8	
	Breach 22 %		2.31 E-7	
PRO2-HE (Propane)	Full bore rupture	188	1.63 E-7	34
	Breach 44 %		3.70 E-7	
	Breach 22 %		8.88 E-7	
PRO2-EF (Propane)	Full bore rupture	3576	3.22 E-7	158
	Breach 44 %		7.32 E-7	
	Breach 22 %		1.76 E-6	

Scenarios with safety systems

The following assumptions are made for the influence of the safety systems:

- (Safety system 1) The gas detection will close the valve in 2 minutes, with a probability of failure equal to 0.01.
- (Safety system 2) In case of failure of this first safety system, an operator can push on an emergency button, with a time reaction of 10 minutes and the closing of another valve (the first safety system could fail due to the non closing of a valve). Probability of failure of this second safety system: 0.01.

Details about involved safety systems and resulting scenarios are shown in Figure A5-6 and Table A5-13.

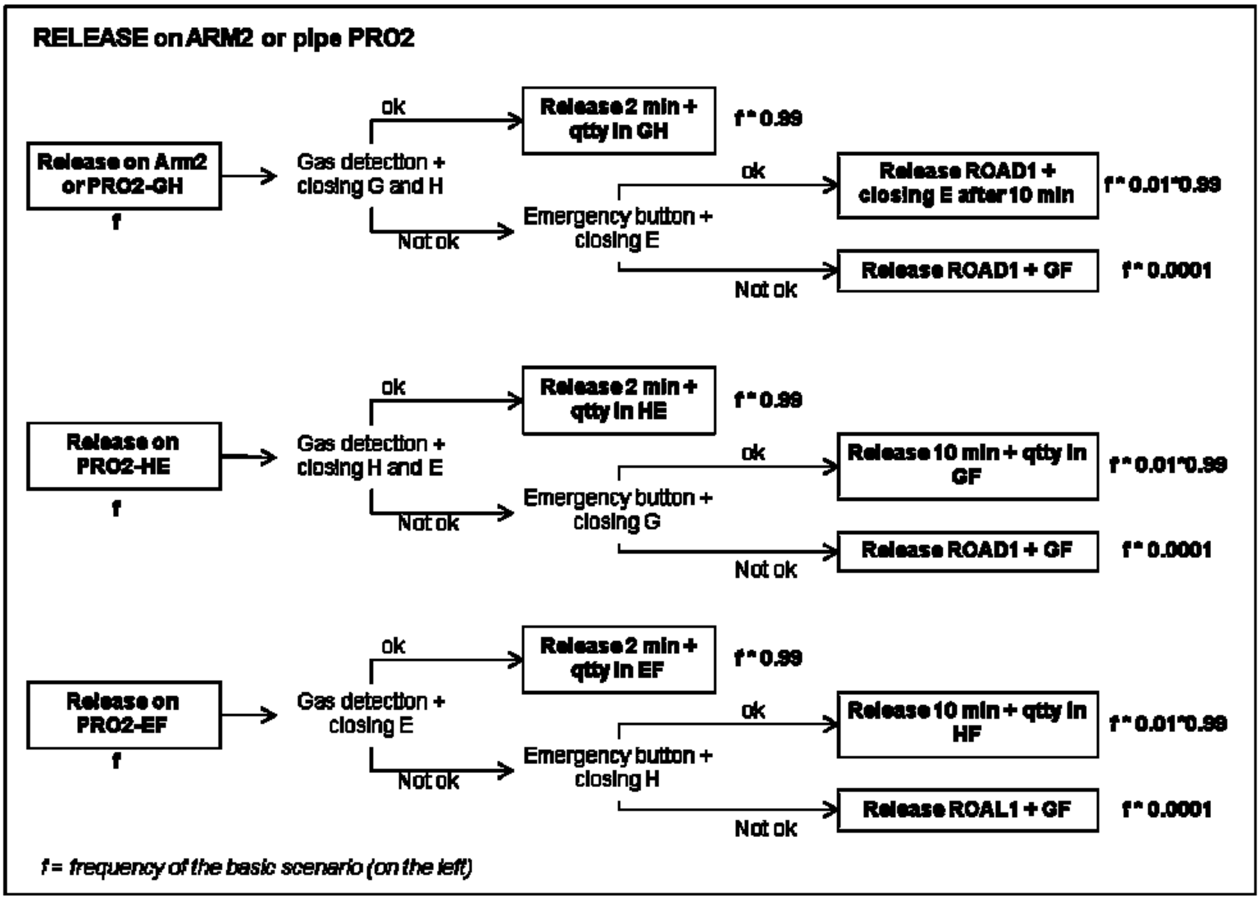

Figure A5-6 Influence on safety systems on scenarios on ARM2 and pipe PRO2

Table A5-13 Scenarios for PRO2 (with safety systems)

Part	Scenario (SSi = successful action of safety system i)	Frequency (/y)	Release conditions	Release location (m)
Arm2 (Propane)	Full bore rupture SS1	4.01 E-6	Release during 2 min + quantity in GH	2
	Full bore rupture SS2	4.01 E-8	Release of the quantity in ROAD1 + closing E after 10 min	
PRO2-GH (Propane)	Full bore rupture SS1	4.20 E-8	Release during 2 min + quantity in GH	5
	Breach 44 % SS1	9.54 E-8	Release during 2 min + quantity in GH	
	Breach 22 % SS1	2.29 E-7	Release during 2 min + quantity in GH	
PRO2-HE (Propane)	Full bore rupture SS1	1.61 E-7	Release during 2 min + quantity in HE	34
	Breach 44 % SS1	3.66 E-7	Release during 2 min + quantity in HE	
	Breach 22 % SS1	8.79 E-7	Release during 2 min + quantity in HE	
PRO2-EF (Propane)	Full bore rupture SS1	3.19 E-7	Release during 2 min + quantity in EF	158
	Breach 44 % SS1	7.25 E-7	Release during 2 min + quantity in EF	
	Breach 22 % SS1	1.74 E-6	Release during 2 min + quantity in EF	
	Breach 22 % SS2	1.74 E-8	Release during 10 min + quantity in HF	

Remark: in Table A5-13, scenarios whose frequency should be multiplied by 0.0001 are not taken into account because their final frequency should be lower than 1 E-8 and thus they will not be considered for the modelling. Most scenarios including the successful action of the safety system 2 have also a frequency lower than 1 E-8 and are not considered for the modelling.

4.2.8. Liquid pipeline between ST2 and ROAD2 (propane): PRO3

For convenience, pipes are divided in several parts indicated by start and end letters as shown in Figure A5-7.

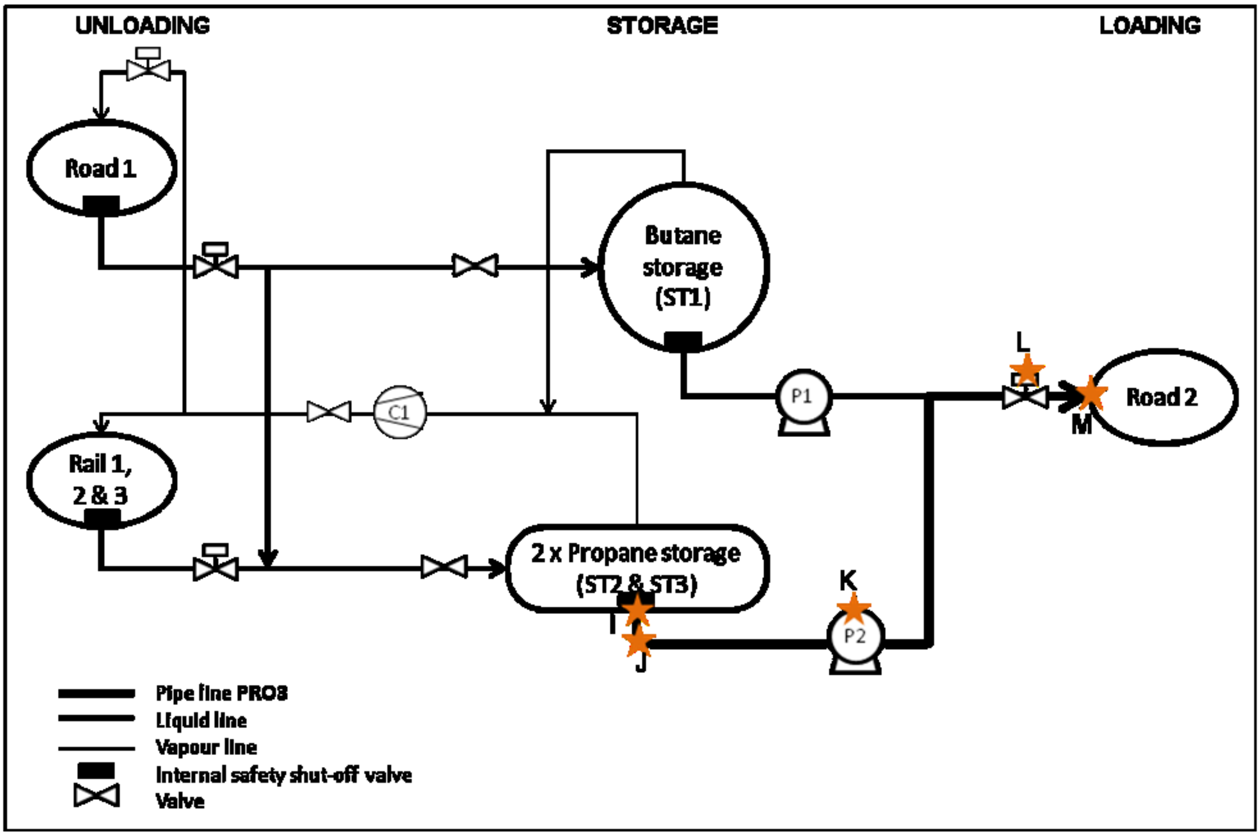

Figure A5-7 Letters to form several parts on pipe PRO3 (from ST2/ST3 to ROAD2)

Data:

- Pipe carrying propane.
- Dimensions as mentioned in Table A5-14.
- Operating conditions: 20°C, saturated liquid before the pump, 22 bar after the pump.
- Flow rate 60 m^3/h.

Table A5-14 Dimensions for pipe PRO3

Part	Diameter (mm)	Length (m)	Volume (m^3)
PRO3-IJ	350	1	0.096
PRO3-JK	250	54	2.651
PRO3-KL	150	200	3.534
PRO3-LM	80	20	0.101

Other equipment:

- Loading arm 3".

Safety systems:

- 1 safety shut off valve at the bottom of the cylindrical storage (point I on Figure A5-7).
- 1 safety valve (point L on Figure A5-7).
- Pump P2 can be stopped (point K on Figure A5-7).
- Safety valves are closed and the pumps and compressors stopped if:

- there is a gas detection;
- or an operator presses on an emergency button.

Even if it is not précised in the plant description, we suppose that there is a physical system to avoid the emptying of the downstream vessel (road tank car ROAD2).

Scenarios without safety systems

The pipeline must be divided in several parts in order to choose release points. These points must be chosen every 100 m in general, and depend on the position of safety valves. Basic scenarios are shown in Table A5-15, without the influence of safety systems in a first step. The calculated frequencies depend on the pipe diameter and length, and also on the number of hours during which the pipe is used (2750 propane loading during 20 minutes, other loadings are negligible for the total duration).

Table A5-15 Scenarios for PRO3 (without safety systems)

Part	Scenario	Quantity between 2 safety valves (kg) or between 1 valve and the pump	Frequency (/y)	Distance between the upstream vessel (Rail1) and the release location (m)
Arm3 (Propane)	Full bore rupture	50	2.75 E-5	273
PRO3-IK (Propane)	Full bore rupture	1371	5.04 E-7	27
	Breach 44 %		1.15 E-6	
	Breach 22 %		2.75 E-6	
PRO3-KL (Propane)	Full bore rupture	1763	3.07 E-6	155
	Breach 44 %		6.98 E-6	
	Breach 22 %		1.67 E-5	
PRO3-LM (Propane)	Full bore rupture	50	5.76 E-7	265
	Breach 44 %		1.31 E-6	
	Breach 22 %		3.14 E-6	

Scenarios with safety systems

The following assumptions are made for the influence of the safety systems:

- (Safety system 1) The gas detection will close the valves and stop the pump in 2 minutes, with a probability of failure equal to 0.01.
- (Safety system 2) In case of failure of this first safety system, an operator can push on an emergency button, with a time reaction of 10 minutes and the closing of another valve or the stopping of the pump (the first safety system could fail due to the non closing of a valve). Probability of failure of this second safety system: 0.01.

Details about involved safety systems and resulting scenarios are shown in Figure A5-8 and Table A5-16.

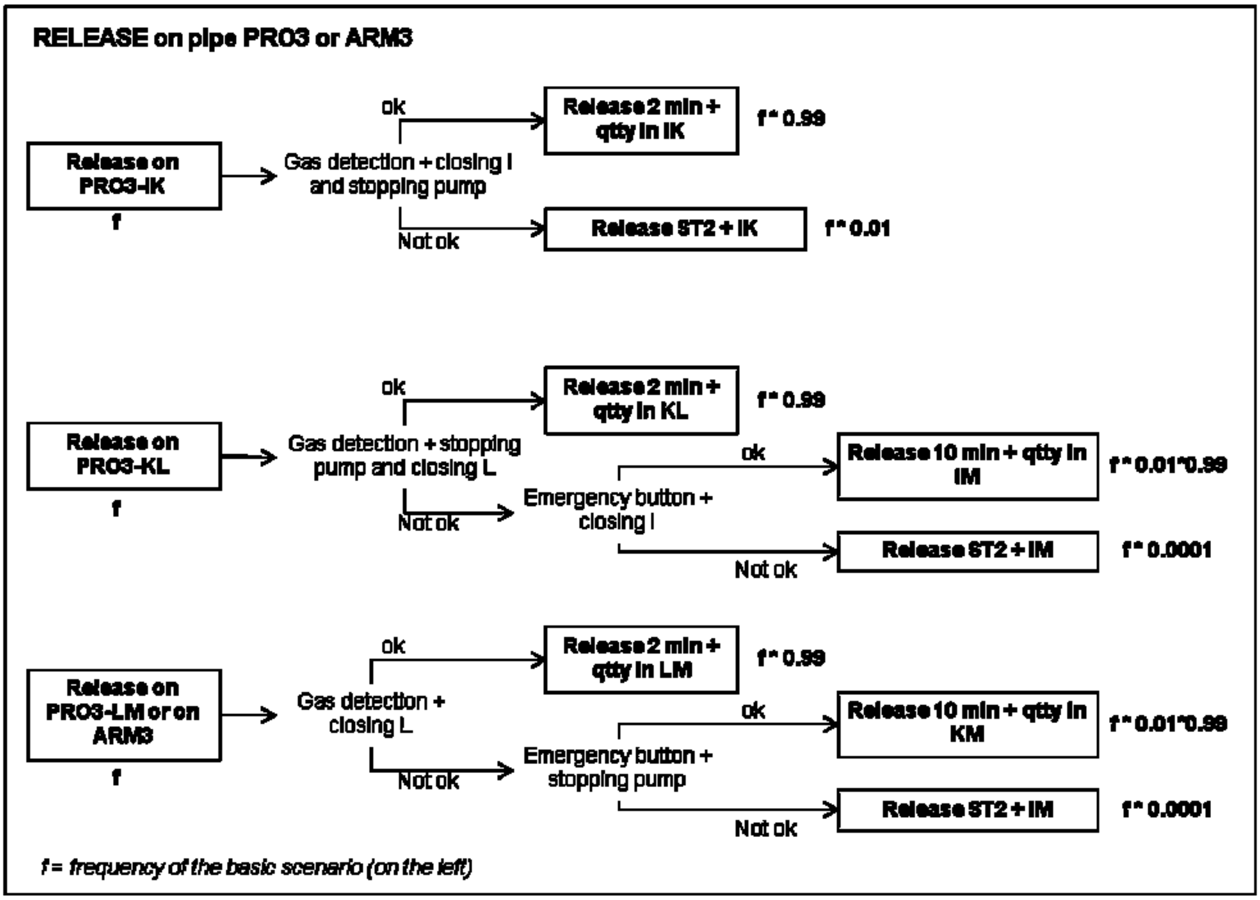

Figure A5-8 Influence on safety systems on scenarios on ARM3 and pipe PRO3

Table A5-16 Scenarios for PRO3 (with safety systems)

Part	Scenario (SSi = successful action of safety system i)	Frequency (/y)	Release conditions	Release location (m)
Arm3 (Propane)	Full bore rupture SS1	2.72 E-5	Release during 2 min + quantity in LM	273
	Full bore rupture SS2	2.72 E-7	Release during 10 min + quantity in KM	
PRO3-IK (Propane)	Full bore rupture SS1	4.99 E-7	Release during 2 min + quantity in IK	27
	Breach 44 % SS1	1.13 E-6	Release during 2 min + quantity in IK	
	Breach 44 % SS2	1.13 E-8	Release ST2 + quantity in IK	
	Breach 22 % SS1	2.72 E-6	Release during 2 min + quantity in IK	
	Breach 22 % SS2	2.72 E-8	Release ST2 + quantity in IK	
PRO3-KL (Propane)	Full bore rupture SS1	3.04 E-6	Release during 2 min + quantity in KL	155
	Full bore rupture SS2	3.04 E-8	Release during 10 min + quantity in IM	
	Breach 44 % SS1	6.91 E-6	Release during 2 min + quantity in KL	
	Breach 44 % SS2	6.91 E-8	Release during 10 min + quantity in IM	
	Breach 22 % SS1	1.66 E-5	Release during 2 min + quantity in KL	
	Breach 22 % SS2	1.66 E-7	Release during 10 min + quantity in IM	
PRO3-LM (Propane)	Full bore rupture SS1	5.7 E-7	Release during 2 min + quantity in LM	265
	Breach 44 % SS1	1.29 E-6	Release during 2 min + quantity in LM	
	Breach 44 % SS2	1.29 E-8	Release during 10 min + quantity in KM	
	Breach 22 % SS1	3.11 E-6	Release during 2 min + quantity in LM	
	Breach 22 % SS2	3.11 E-8	Release during 10 min + quantity in KM	

Remark: in Table A5-16, scenarios whose frequency should be multiplied by 0.0001 are not taken into account because their final frequency should be lower than 1 E-8 and thus they will not be considered for the modelling. Some scenarios including the successful action of the safety system 2 have also a frequency lower than 1 E-8 and are not considered for the modelling.

4.2.9. Pump P2

Data:

- Substance: propane.
- Centrifugal pump.
- Operating conditions: 22 bar.
- Between ST2 and ROAD2.
- Per year (each time during 20 min):
  - 2750 propane loading (21 m³);
  - 15 propane loading (47 m³);

- 35 butane loading (21 m³);
- We will assume that the pump is used 2750 * 20 minutes per year, other loadings are negligible for the total duration.

- Loading flow rate: 60 m³/h.

Scenarios without safety systems:

Table A5-17 Scenarios for Pump P2 (without safety systems)

Scenario	Frequency (/y)	Comments
Catastrophic rupture	1.05 E-5	= 1 E-4 * 2750 * 1/3 / (24*365)
Breach 25 mm	4.60 E-4	= 4.4 E-3 * 2750 * 1/3 / (24*365)

Remark: There are 2 pumps in the system, but the frequency does not need to be multiplied by 2 because the correction factor including the duration of use is already calculated for the total duration of the transfer (both pumps together).

Safety systems:

- (Safety system 1) In case of catastrophic rupture of the pump, it is supposed that the pump stops. Safety system 1 will detect the gas and close the valves (points I and L on Figure A5-7) in 2 minutes. If this system fails, no other valve is available to isolate the release (probability = 0.01).
- (Safety system 1) In case of breach on the pump, it is supposed that the pump still runs. Safety system 1 will detect the gas and close the valves (points I and L on Figure A5-7) in 2 minutes, and also stop the pump. If this system fails, no other valve is available to isolate the release (probability = 0.01).

Scenarios with safety systems:

Table A5-18 Scenarios for Pump P2 (with safety systems)

Scenario (SSi = successful action of safety system i)	Frequency (/y)	Release conditions
Catastrophic rupture SS1	1.04 E-5	Release during 2 min + quantity in IL
Catastrophic rupture	1.04 E-7	Release ST2 + quantity in IM
Breach 25 mm SS1	4.56 E-4	Release during 2 min + quantity in KL
Breach 25 mm	4.56 E-6	Release ST2 + quantity in IM

4.3. Weather data

In Wallonia, the weather data are normally plant-specific and obtained from the nearest weather station. Due to lack of precise data, the weather conditions used in France are chosen: D5 by day and F3 by night. Additional weather parameters have to be defined for the software Phast Risk, and we chose to use default parameters of the software, as shown in Table A5-19.

Table A5-19 Weather parameters

Parameter	Day	Night	Unit
Atmospheric temperature	9.85	9.85	°C
Relative humidity	70	70	%
Solar radiative flux	0.5	0	kW/m²
Wind speed	5	3	m/s
Pasquill stability	D 800 m	F 100 m	
Building exchange rate	4	4	/hr
Tail time	1800	1800	s
Surface	user defined	user defined	
Surface roughness parameter	0.1 (= roughness 183.2 mm)	0.1 (=roughness 183.2 mm)	
Soil temperature	9.85	9.85	°C
Pool temperature	9.85	9.85	°C

4.4. Location of the equipment

Two cases are studied: the first one considers that all equipment are located on the same spot (case A); and the second one considers that the equipment are located along a line (case B). Both situations are depicted in Figure A5-9. A third case is considered by other partners, but this third hypothesis is only linked with the proximity between the plant and populated areas. This will influence the societal risk, but our methodology does not take this one into account. For this reason, the third case is not studied in this report.

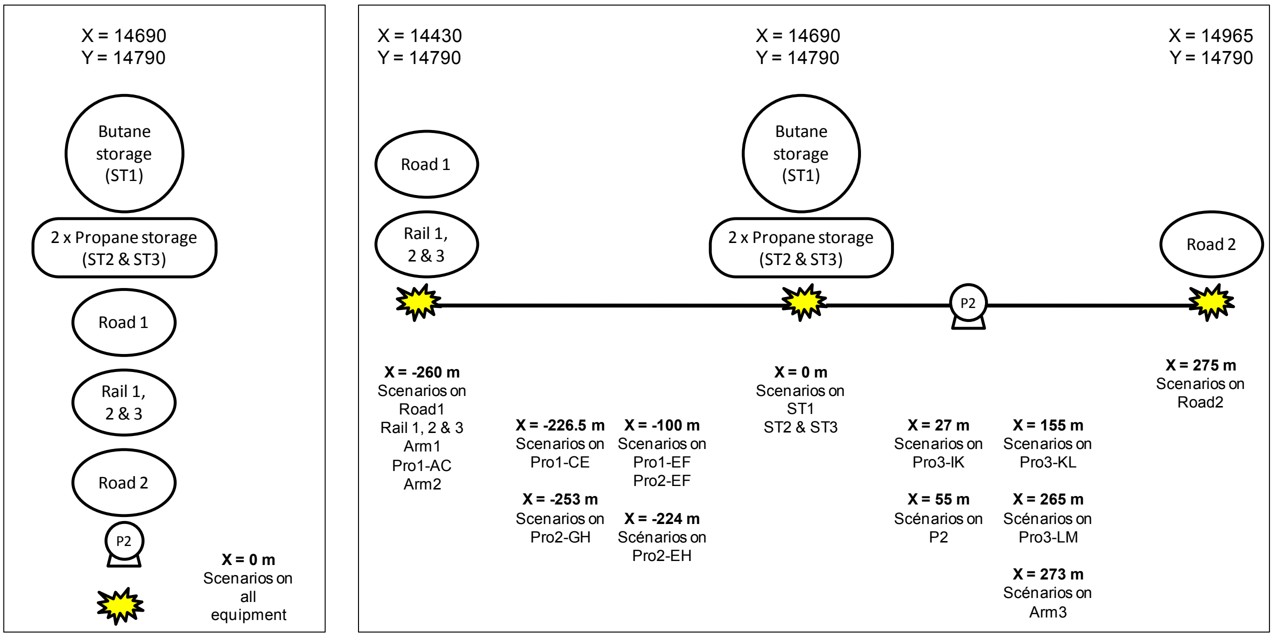

Figure A5-9 Location of equipment (Case A, on the left, and Case B, on the right)

4.5. Ignition data

In the Walloon methodology, a map of ignition sources must be defined on the basis of site-specific data. Different kinds of ignition sources (inside and outside the plant) are noted on the "ignition map":

- "Point" ignition sources as furnaces, flares, etc.
- "Line" ignition sources as roads.
- "Polygon" ignition sources as process areas, neighbouring population areas, buildings, etc.

The Walloon methodology does not use pre-defined probability of delayed ignition. This is calculated by the software, which compares the path followed by the flammable cloud and the ignition map.

Due to the lack of data in the description of the plant, an assumption was made concerning the ignition map. According to the location of equipment shown in case B (see Figure A5-9 – right), the plant seems to have an extent equal to 600 m. For the ignition area and map, we have then considered an "industrial area", circular-shaped, with a radius of 300 m, and centred on the butane and propane storage (X = 14690; Y = 14790). The ignition probability for the industrial area is set equal to 0.05 according the Walloon methodology. The same ignition map is used for both cases (A and B).

4.6. Other information

Calculations are performed with the software Phast-Risk 6.53.1.

5. Results

5.1. Case A (all the equipment on the same spot)

For the Case A, the iso-risk curves are shown on Figure A5-10 and the risk profile (individual risk versus distance) is shown in Figure A5-11.

Iso-risk curves use a colour code presented in Table A5-20.

Table A5-20 Colour of iso-risk curves

Colour	Individual risk
Yellow	10^{-2}/year
Black	10^{-3}/year
Purple	10^{-4}/year
Turquoise blue	10^{-5}/year
Red	10^{-6}/year
Green	10^{-7}/year
Blue	10^{-8}/year

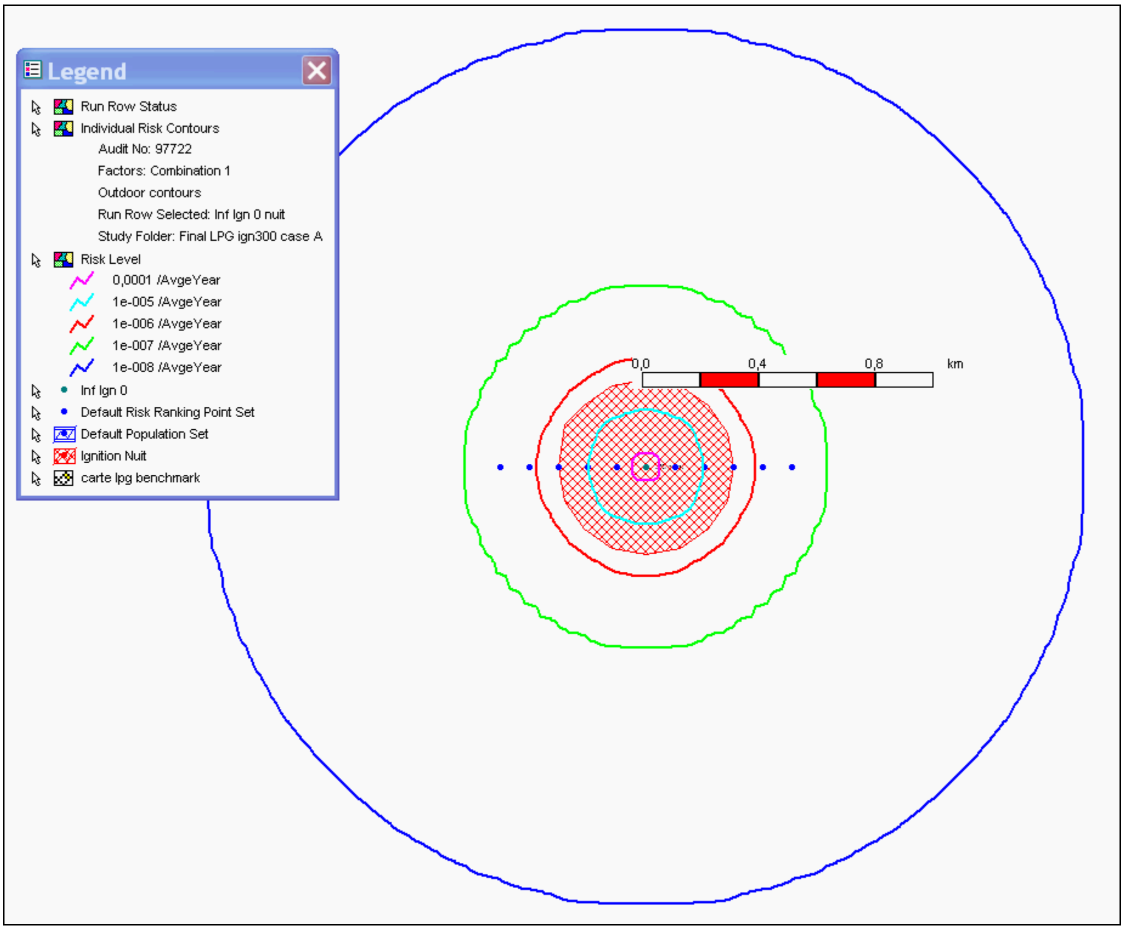

Figure A5-10 Iso-risk curves centred on the LPG plant (case A)

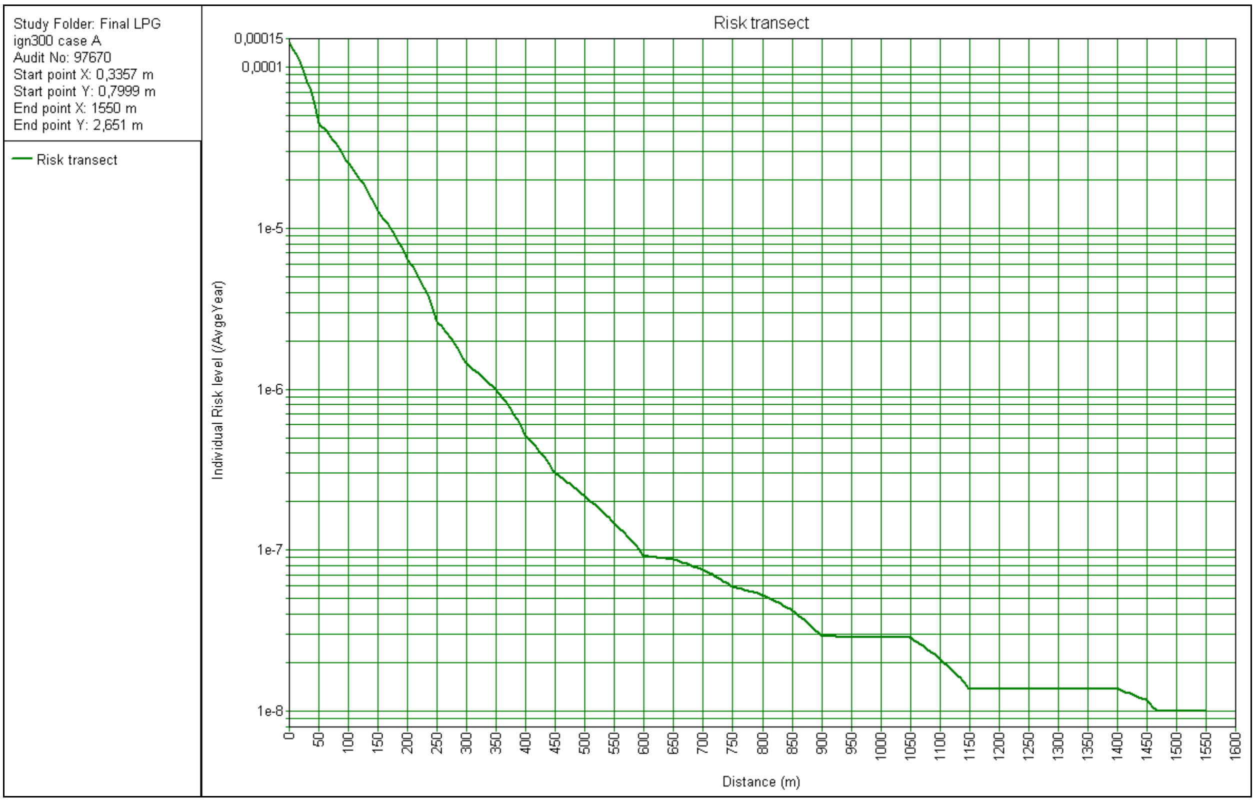

Figure A5-11 Risk profile (individual risk versus distance) (Case A)

Concerning land use planning decision, it must be pointed out that houses are authorized on spots where the individual risk is lower than 1E-5 per year, while sensitive buildings like hospitals, schools, rest homes, etc, will be authorized on spots where the individual risk is lower than 1E-6 per year. The corresponding distances are summarized in Table A5-21.

Table A5-21 LUP distances (Case A)

Type of building	Authorized if the distance between the building and the LPG plant is higher than … (in m)
Type C (e.g. houses)	170 m
Type D (e.g. hospitals, schools, etc)	350 m

5.2. Case B (all the equipment along a line)

For the Case B, the iso-risk curves are shown on Figure A5-12 and the risk profile (individual risk versus distance) is shown in Figure A5-13 for the right part of the plant, and in Figure A5-14 for the left part of the plant.

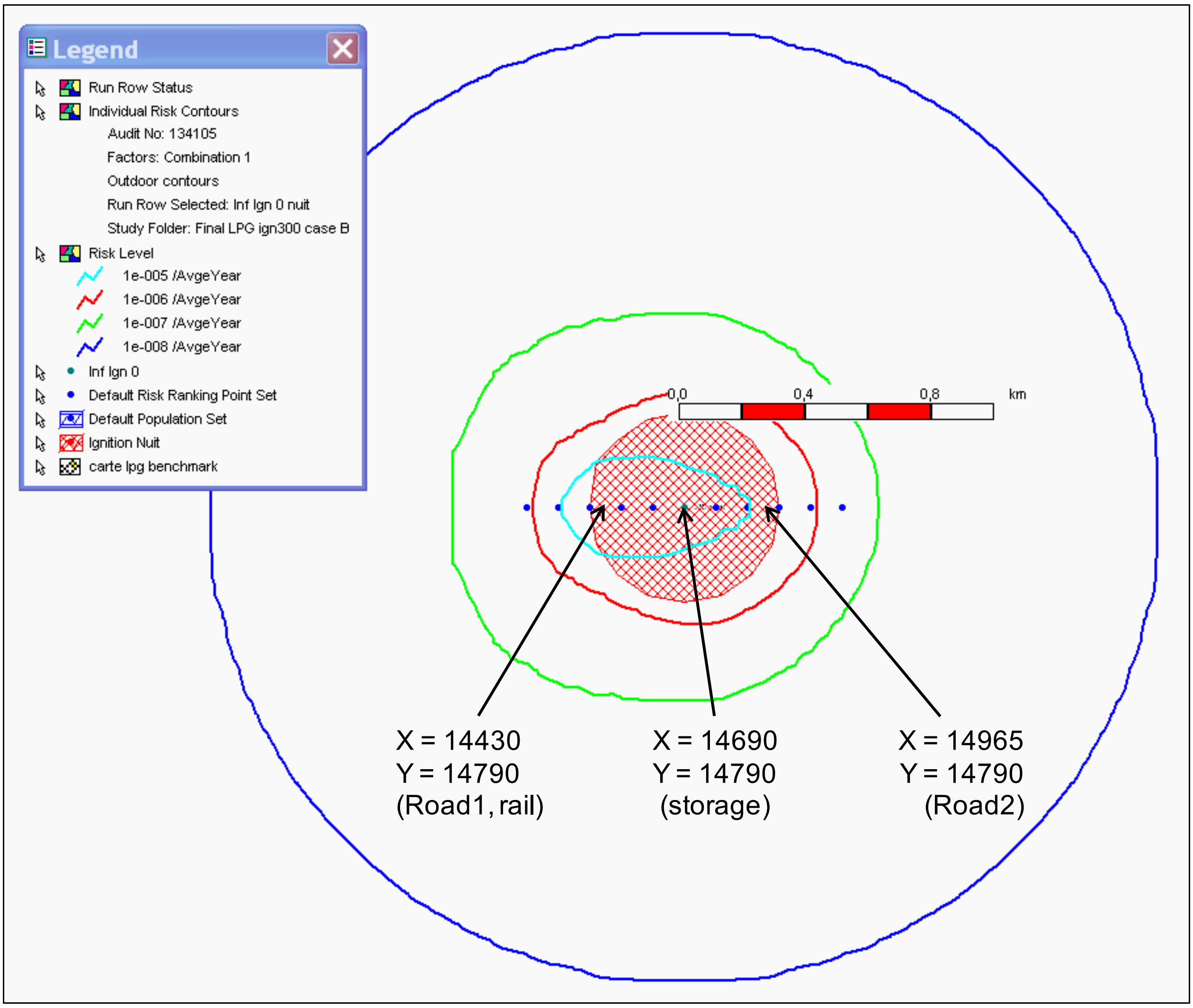

Figure A5-12 Iso-risk curves for the LPG plant (case B)

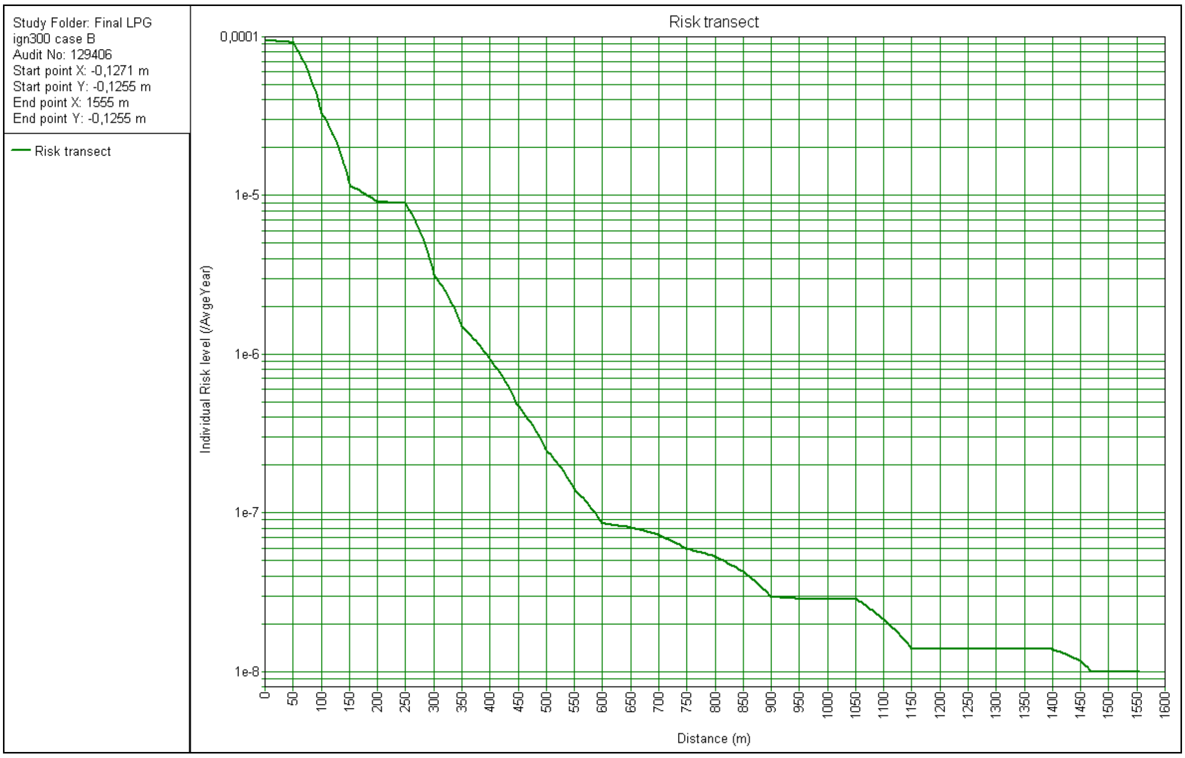

Figure A5-13 Risk profile (individual risk versus distance) (Case B) – Point 0 is the location of the storage and the X-axis is directed towards the right of the plant, so that X = 275 m is the location of Road2 (loading station).

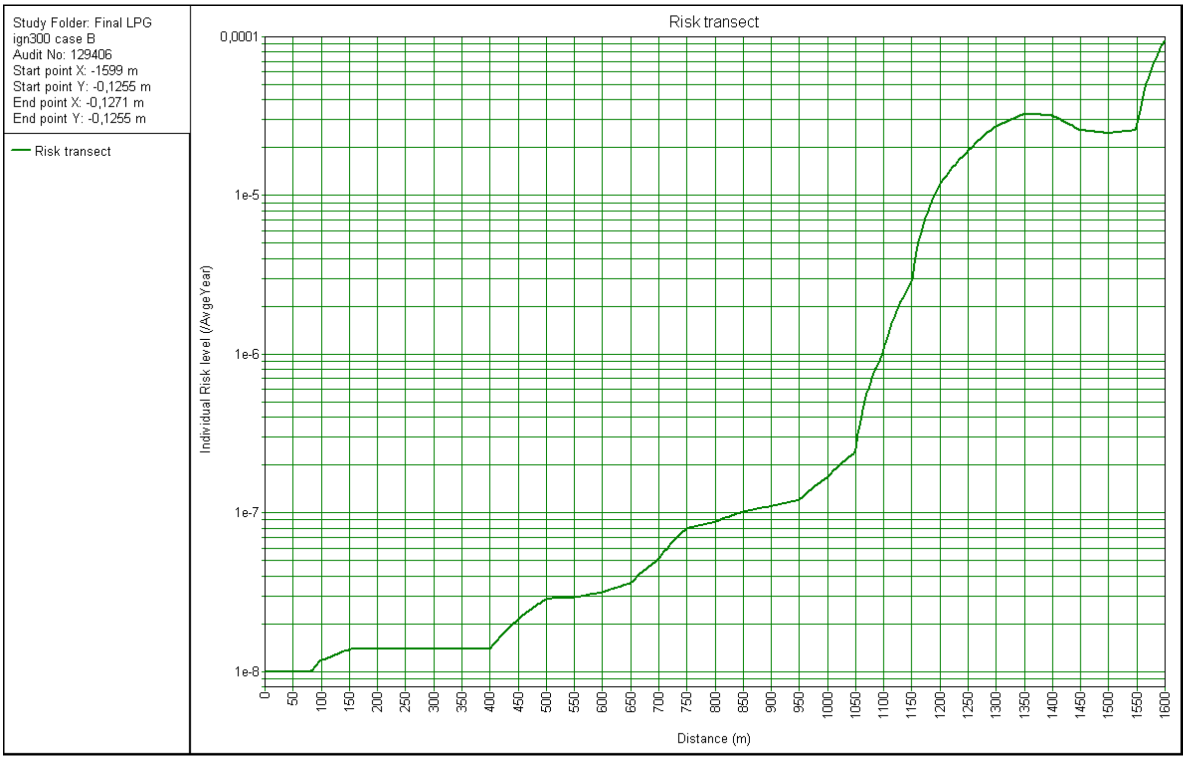

Figure A5-14 Risk profile (individual risk versus distance) (Case B) – Point "X=1600 m" is the location of the storage and the X-axis decreases towards the left of the plant, so that X = 1340 m is the location of Road1 and Rail1, 2 & 3 (unloading station).

Concerning land use planning decision, it must be pointed out that houses are authorized on spots where the individual risk is lower than 1E-5 per year, while sensitive buildings like hospitals, schools, rest homes, etc, will be authorized on spots where the individual risk is lower than 1E-6 per year. The corresponding distances are summarized in Table A5-22.

Table A5-22 LUP distances (Case B)

Type of building	**Authorized if the distance between the building and the centre of the LPG plant (location of the storage) is higher than … (in m)**	
	Left side	Right side
Type C (e.g. houses)	410 m	175 m
Type D (e.g. hospitals, schools, etc)	500 m	400 m

Differences between left and right side of the plant are due to the geographical dispersion of the equipment, which does not appear in case A.

5.3. Main scenarios

The software used (Phast Risk 6.53.1) allows us to define "risk ranking points", which means locations where the scenarios contributing mainly to the risk are identified. We chose to define points every 100 m, left and right of the centre of the plant (storage). 5 points are defined on the left-side of the plant, and also 5 points on the right-side. These locations are marked by blue dots on Figure A5-10 (case A) and Figure A5-12 (case B). It must be reminded that, in case B, the unloading station is located on the left-side, while the loading station is located on the right side.

Results are shown in Table A5-23.

Main conclusions are: (see Figure A5-2 for the labelling of equipment)
CASE A

- At shorter distance of the installations (located on point 0 m), the main contributing scenario is the full bore rupture of the unloading Arm 1.
- At middle distance (between 200 and 400 m), the catastrophic rupture of pump P2 contributes mainly to the risk (this scenario is important because its frequency is rather high and the breach diameter is large: 250 mm).
- At longer distance (between 300 and 500 m), the catastrophic rupture of the butane storage (including the Bleve) and, in a lesser extent, the catastrophic rupture of the propane storage (without Bleve) are predominant.

CASE B

- On the left side of the plant (unloading station – side), the predominant scenario is the full bore rupture of the unloading Arm 1. At longer distance (from 500 m), the catastrophic rupture of storage vessels contributes more and more to the individual risk.
- On the right side of the plant (loading station – side), the catastrophic rupture of pump P2 is the preponderant scenario, together with the catastrophic rupture of storage vessels at longer distance (from 400 m).
- At 300 m right side, the local effect of the loading station can be observed since the main contributing scenario is the full bore rupture of the loading Arm 3.

Table A5-23 Risk Ranking Points

	Case A		Case B	
Point	**Main contributing scenarios**	**Percentage of the risk (%)**	**Main contributing scenarios**	**Percentage of the risk (%)**
500 m left side	Idem 500 m right side		Arm1 full bore rupture SS1 ST1 Cata. rupture ST2 Cata. rupture	44.41 27.03 12.90
400 m left side	Idem 400 m right side		Arm1 full bore rupture SS1 PRO1-EF Br44 SS1 ST1 Cata. rupture	67.20 7.07 5.42
300 m left side	Idem 300 m right side		Arm1 full bore rupture SS1	63.15
200 m left side	Idem 200 m right side		Arm1 full bore rupture SS1 PRO1-EF Br44 SS1	47.24 11.52
100 m left side	Idem 100 m right side		PRO1-EF Br22 SS1 PRO1-EF Br44 SS1 Arm1 full bore rupture SS1	32.97 21.77 11.60
100 m right side	Arm1 full bore rupture SS1 Pump P2 cata. rupture SS1 PRO1-EF Br44 SS1	44.55 13.31 11.79	Pump P2 Br25mm SS1 Pump P2 cata. rupture SS1	83.28 5.99
200 m right side	Pump P2 cata. rupture SS1 Arm1 full bore rupture SS1 PRO1-EF Br44 SS1	36.57 26.61 13.84	Pump P2 cata. rupture SS1 PRO3-KL Br22 SS1	40.29 22.31
300 m right side	Pump P2 cata. rupture SS1 PRO1-EF Br44 SS1 ST1 Cata. rupture	45.15 16.83 13.68	Arm3 full bore rupture SS1 Pump P2 cata. rupture SS1	57.16 25.16
400 m right side	Pump P2 cata. rupture SS1 ST1 Cata. rupture ST2 Cata. rupture	44.40 35.98 10.44	Pump P2 cata. rupture SS1 ST1 Cata. rupture	54.60 24.04
500 m right side	ST1 Cata. rupture ST2 Cata. rupture Rail1 Cata. rupture	58.15 27.76 10.75	ST1 Cata. rupture Pump P2 cata. rupture SS1 ST2 Cata. rupture	40.97 31.82 19.56

6. Sensibility of results

6.1. Sources of delayed ignition

The results shown in paragraph 5 are based on the assumptions explained in part 4. Most assumptions are linked to our methodology of quantification of the external risk. However, one important data is the ignition map, which will define and influence all the "Vapour Cloud Explosion" scenarios.

The delayed ignition sources are not mentioned in the description of the plant. As a first assumption, we chose to consider a circle-shaped ignition zone, whose diameter is equal to 600 m and which is centred on the LPG plant. This diameter is chosen so that the ignition zone is representative of the extent of the plant. The ignition probability is set equal to 0.05, which is the value used in our modelling for industrial areas.

Results associated with this assumption were presented in Table A5-21 and A5-22.

In a second step, we decided to modify the ignition sources in order to discuss the importance of this assumption. The QRA was performed for case A with different ignition zones: an ignition circle with different radius (50, 150, 250 and 350 m), no ignition zone, and a "random" ignition zone depicted in Figure A5-15. In each case, each ignition zone has the same ignition probability (0.05).

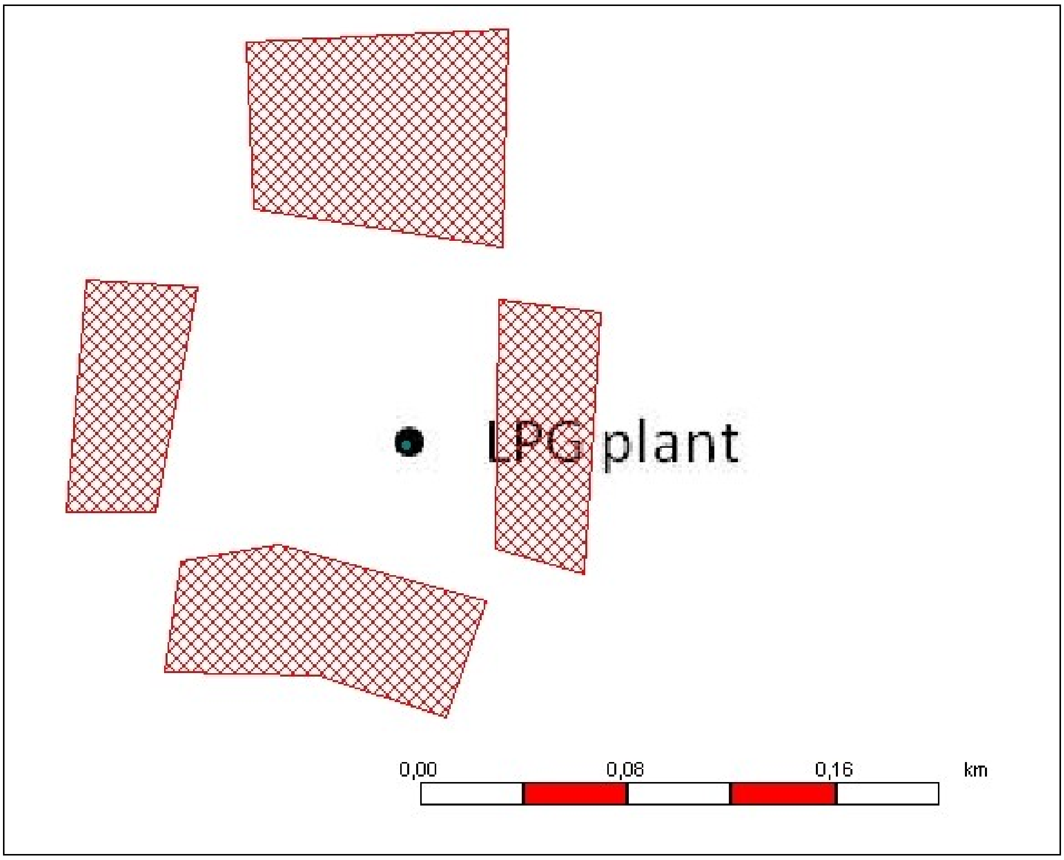

Figure A5-15 "Random" ignition zone

Table A5-24 LUP distances depending on the delayed ignition sources

Ignition zone	Distance to first allowed building type C (e.g. houses) – iso-risk curve 1E-5 /year	Distance to first allowed building type D (e.g. hospitals, schools, etc) – iso-risk curve 1E-6 /year
No	90 m	210 m
Circle radius 50 m	95 m	220 m
Circle radius 150 m	100 m	220 m
Circle radius 250 m	170 m	330 m
Circle radius 350 m	170 m	360 m
Random (Figure A5-15)	140 m	240 m

The land use planning distances depending on the ignition sources considered are summarized in Table A5-24. It can be observed that the choice of the ignition sources is important, since distances between the centre of the plant and the first authorized houses vary between 90 and 170 m, so they can turn out to be twice as high.

This sensibility was borne in mind when calculating the external risk in chapter 5.

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