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A comparison of two risk assessments

Bilthoven (The Netherlands)

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Abstract

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In France and in the Netherlands, regulations apply to determine the risk of companies with toxic, flammable or explosive substances and mixtures to the surroundings. The outcomes of risk calculations are used for permit granting and for land-use planning. The way in which risk is calculated in France and in the Netherlands, differs significantly. The regulatory framework is different and technical hypotheses vary. Nevertheless, the risk outcomes for a fictitious storage depot of flammable liquids show considerable similarity.

This is the result of a study carried out by the French INERIS and the Dutch RIVM. Public authorities can use the findings of this study to evaluate their frameworks for risk calculation.

For this study, the risk of a fictitious storage depot of flammable liquids was calculated in accordance with the French and Dutch regulations. Several significant differences were observed. Differences in policy framework involve the norms for acceptance of risk and the way in which outcomes are used for permit granting and land-use planning. Furthermore, the methodology to be used is laid down in legislation in The Netherlands, while in France the methodology is chosen and justified by the permit-holder. Technical differences relate to the accident scenarios used, the probabilities assigned to these accident scenarios and the size of the area where damage may occur.

The area where vulnerable objects are undesirable and where future vulnerable objects should be avoided is largely the same in the two risk assessments. The area where severe consequences from a potential accident have to be considered is comparable as well.

Keywords:
risk assessment, flammable liquids, storage, Seveso Directive

Rapport in het kort

Benchmark studie voor een opslag van ontvlambare vloeistoffen
Een vergelijking van twee risicobeoordelingen

In Frankrijk en in Nederland is regelgeving van kracht om te bepalen wat het risico is van bedrijven met giftige, ontvlambare of explosieve stoffen voor de omgeving. De uitkomsten van risicoberekeningen worden gebruikt voor vergunningverlening en voor ruimtelijke ordening. De wijze waarop deze landen risico's berekenen, verschilt aanzienlijk. De beleidsmatige context verschilt en technische aannames lopen uiteen. Desalniettemin komen de uitkomsten voor een fictieve opslag van ontvlambare vloeistoffen op hoofdlijnen grotendeels overeen.

Dit blijkt uit onderzoek van RIVM en het Franse INERIS. Beleidsmakers kunnen de bevindingen van het onderzoek gebruiken om de uitgangspunten voor het maken van risicoberekeningen nader te evalueren.

Voor het onderzoek is het risico van een fictief opslagdepot met ontvlambare vloeistoffen berekend volgens de Franse en de Nederlandse regelgeving. Hierbij zijn meerdere significante verschillen geconstateerd. Beleidsmatig verschillen de normstelling en de manier waarop uitkomsten worden gebruikt in de vergunningverlening en de ruimtelijke ordening. Verder is de te gebruiken rekenmethodiek in Nederland in regelgeving vastgelegd, terwijl in Frankrijk de vergunningaanvrager de rekenmethodiek kiest en verantwoordt. In technisch opzicht verschillen de ongevalsscenario's die worden gehanteerd, de veronderstelde kansen voor verschillende typen ongevallen en de omvang van het gebied waar schade optreedt.

In de uitkomsten voor de twee landen is het gebied waar bestaande kwetsbare objecten ongewenst zijn en waar toekomstige kwetsbare objecten vermeden moeten worden grotendeels gelijk. Ook het totale gebied waarin rekening gehouden moet worden met ernstige gevolgen van een eventueel incident is vergelijkbaar.

Trefwoorden:
risicobeoordeling, ontvlambare vloeistoffen, opslag, Seveso-richtlijn, BRZO-richtlijn

Synthèse

Benchmark sur le cas d'un dépôt de liquide inflammable
Une comparaison de deux évaluations des risques

Aux Pays-Bas et en France des réglementations imposent l'évaluation et la maîtrise des risques générés par les établissements utilisant des substances dangereuses (toxiques, inflammables ou explosives). Les résultats de ces évaluations sont notamment utilisés par l'administration pour autoriser l'exploitation de ces établissements et pour maîtriser l'urbanisation autour de ces sites. Ces évaluations de risque sont réalisées de manière différente aux Pays-Bas ou en France. Le cadre réglementaire est également différent et les hypothèses et les méthodes de calculs varient. Néanmoins, leurs résultats dans l'exemple des dépôts de liquides inflammables montrent des similarités considérables.

Ce rapport présente le résultat d'une étude menée par l'INERIS et le RIVM. Les autorités peuvent utiliser les résultats de cette étude pour se construire une opinion sur les évaluations de risque.

Dans le cadre de cette étude, le risque généré par un dépôt de liquide inflammable fictif a été calculé en concordance avec les réglementations française et hollandaise. Quelques différences significatives ont été observées. Les différences existantes dans le cadre réglementaire concernent notamment les niveaux d'acceptabilité du risque et la manière dont les résultats des calculs sont utilisés pour délivrer le permis d'exploitation et lors de la définition des actions à mener pour la maîtrise de l'urbanisation. Elles concernent également les méthodologies de calcul utilisées: alors que celle-ci est imposée dans la réglementation aux Pays-Bas, en France, cette méthodologie est choisie et justifiée par l'industriel. Les différences techniques relevées dans les modes de calcul sont liées aux scénarios d'accident évalués, leur probabilité et les dimensions estimées des zones où des dommages pourraient se faire ressentir.

Enfin, les résultats de ces deux approches montrent que les zones où les constructions vulnérables sont considérées comme indésirables et les zones où leur implantation future doivent être évitées sont largement les mêmes, que ce soit aux Pays-Bas ou en France. De même, les zones où il est estimé qu'un accident majeur pourrait entraîner des conséquences graves sont comparables.

Mots clés
évaluation des risques, liquides inflammables, stockage, directive Seveso

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Summary

In France and in the Netherlands, risk calculations are carried out to determine hazardous areas around Seveso companies. In both countries, industries are responsible for carrying out the risk calculations. Public authorities are responsible to check the quality of the risk assessment. The regulatory context differs between France and the Netherlands. A benchmark exercise was carried out by INERIS and RIVM to compare the two approaches. This benchmark comprises a fictitious storage facility for flammable liquids (upper tier Seveso II), with fictitious surroundings.

The framework for risk calculations
In France risk calculations can be carried out at all times. It is prescribed to use probability ranges for the likelihood of incidents and intensity and severity scales for the consequences of incidents. Companies are free to choose their preferred methodology for the selection of scenarios and probability ranges and to choose appropriate models for consequence analysis. These choices have to be justified in the safety report and are assessed by the public authorities.
In the French context, two indicators are used for policy decisions; the risk matrix is used for the permitting process and the set of aléa zones is used for land-use planning. In the risk matrix, the likelihood of scenarios is set out against the number of people exposed to undesirable consequence levels. If too many scenarios are in the intolerable region and additional safety measures cannot resolve this situation, the permit to operate could not be supplied for a new situation and could be withdrawn for an existing situation. The set of aléa zones is a set of seven areas in which consequences of different intensity and different frequency are expected. Specific requirements for land-use are defined for each of these seven zones. A distinction is made between existing constructions and new developments. In the highest risk area existing house owners should be expropriated and new constructions are banned. Additional safety measures can also be discussed in a debate between various stakeholders in the context of the formulation of the Plan de Prévention des Risques Technologiques (PPRT) if their costs are lower than land-use planning measures (such as expropriation).

In the Netherlands risk calculations are only relevant when a policy decision is required by legislation, for example when there is a request for an environmental permit (new activity), when there is a request for a change in the permit (change of activities), when there is a request for a change in the zoning scheme and when the relevant risk calculation methodology changes. The methodology for the realisation of the risk calculations and the software to be used are both prescribed by regulations.
In the Netherlands, two indicators are used for policy decisions as well. The first indicator, individual risk, is defined as the likelihood that a fictitious person at a certain location will die as a consequence of an incident at the industry. Individual risk is a spatial indicator and decreases with distance. Strict limitations for existing constructions and new spatial developments apply within the zone where the individual risk exceeds 10^{-6} per year. New activities that generate a conflict will not be allowed for and existing conflicting situations should be resolved within terms defined by legislation. The second indicator, societal risk, is a graph in which the

likelihood of an incident with a certain number of fatalities is shown for different numbers of fatalities. The competent authority then needs to define a number of risk mitigation measures, including technical measures at the industry, relocation of the industry and modifications in the land-use around the industry. Subsequently, the competent authority must assess with stakeholders the desirability of each of these measures, in terms of costs and expected amount of risk reduction, and give a public account of the outcomes for the local council.

In relation to the above, the following differences were observed:

- Different indicators are used as a basis for policy decisions on land-use planning and permitting. In the Netherlands public decision tools use the IR 10^{-6} contour and the FN-curve. The French public decision tools use 'aléa zones' and risk matrices.
- In the Netherlands, the methodology and software to be used are laid down in legislation. In France, the framework of the risk assessment is prescribed, but the specific methodology and software to be used, is a choice to be made by the industry. This choice has to be justified in the safety report and is assessed by the public authorities.
- With respect to land-use planning, seven zones are distinguished in France, each with specific limitations on existing and future land-use. In the Netherlands, only two regions are distinguished. In the inner zone (IR 10^{-6} per year) very strict limitations on existing and future land-use apply. In the outer zone (the envelope where incidents may have lethal consequences), land-use limitations and safety requirements for constructions are negotiated by the competent authority and other stakeholders.
- With respect to the permitting process, in France, risk calculations are carried out when the safety report is updated. The outcomes of this process could result in the withdrawal of a permit or in a demand for additional safety measures. In the Netherlands, the acceptability of risk will only be assessed when a change in the permit or the zoning scheme is requested or when the risk calculation methodology changes.

Outcomes for the flammable liquid depot
Risk assessments were carried out by INERIS and RIVM for the French and Dutch context respectively. INERIS has based a number of its choices on guidelines edited by the relevant French ministry or by a national working group on storage of flammable liquids. Other choices were based on tools developed by INERIS. RIVM made use of the prevailing Dutch guideline.

Figure 1 presents the map with French aléa levels and Dutch individual risk contours. From a general point of view, both methodologies identify the same areas with a 'high risk' and a 'low risk'. In more detail, several interesting differences were observed. The most important difference involves the different selection of scenarios considered to be relevant for the risk assessment. This difference can be explained by differences in legislative context and by different aims attached to the risk assessment. In France, the identification of scenarios aims to be exhaustive and the calculated consequences must be representative. In the Netherlands, emphasis is laid on the reproducibility of outcomes and overall reliability of the method.

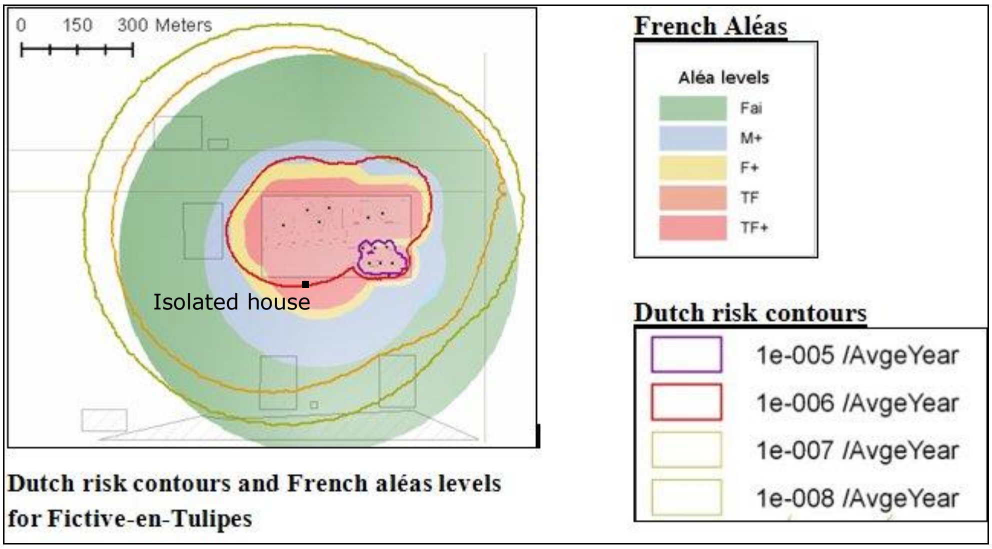

Figure 1 Spatial distribution of risk (INERIS and RIVM approach)

Concerning the existing land-use, both methodologies underline a problem with a single isolated house just south of the facility. In the French regulatory context, this individual house would be expropriated through the PPRT. The PPRT may also implement additional measures for existing buildings in blue and green areas, such as an increased resistance of structures and windows to overpressure effects. The costs for all these measures will be divided between the local authority, the industry, real estate owners and the state. In the Dutch regulatory context, the house just south of the facility is highly undesirable, but there is no formal requirement for expropriation or relinquishment. Safety measures to existing buildings outside the IR 10^{-6} contour may be desired. However, as long as there is no change in activities on the depot, these measures must be paid for by the local council. As the current societal risk is well below the guide values, it is unlikely that the council will demand for such additional safety measures.

Regarding future land-use, new constructions are strictly banned in the red and yellow zones (France) and the IR 10^{-6} contour (Netherlands). The map above shows a remarkable match between these two areas. In more distant regions, the French PPRT will probably introduce some land-use restrictions in blue, green and low kinetic areas (not shown in Figure 1). These restrictions will mainly concern the type, the density and the design of buildings. In the Dutch regulatory context, changes in the zoning scheme in the surroundings of the facility must be accounted for by the competent authority, with reference to the increase of risk generated by the new land-use. As the calculated societal risk is well below the Dutch 'guide values', small new developments will probably be accepted.

Finally, for the permit to operate, the French risk matrix shows an ALARP situation. It could be asked to the operator to improve its safety level on the basis of safety improvements proposed in the safety report. Within the Dutch context there are no formal obligations to the permit. The permit will generally make reference to industrial standards, in such a way that good practise is sufficiently incorporated.

1 Introduction

In France and in the Netherlands, risk calculations are carried out to determine hazardous areas around Seveso companies. 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 differ between France and the Netherlands. A benchmark exercise was carried out to compare the French and Dutch approaches. This benchmark comprises a fictitious storage facility for flammable liquids (upper tier Seveso II) in fictitious surroundings.

This report includes a description of the regulatory context in France and in the Netherlands, a description of the methodologies used to calculate risk, a description of the installations in the facility, a description of the outcomes for the French and Dutch approach, and a comparison of both the methods and the outcomes.

This report does not deal with local emergency plans and public information in the vicinity of Seveso establishments.

The work carried out by INERIS was commissioned by the French ministry MEDDTL (Ministère de l'Ecologie, du Développement durable, des Transports et du Logement). The work carried out by RIVM was financed by the Strategic Research Programme RIVM.

A similar benchmark study for a storage of LPG was recently carried out by INERIS, RIVM, HSE and FPMs (see [1], [2]).

2 Legislative context and technical methodology

In the current chapter, the French regulatory context and Dutch regulatory context are described and compared. Specific attention is paid to the methodologies used to calculate third party risk.
The description of the regulatory contexts applies to Seveso companies in general. The description of methodologies focuses on the storage of flammable liquids.

2.1 French regulatory context

This section deals with the following issues:
- the classification of industrial activities in France with regard to Seveso establishments;
- the requirements for the safety report in France and the public decision-making process related to this document;
- the acceptance levels used in France;
- the methodology used for the realisation of a safety report.

2.1.1 Scope of regulations (which types of industries?)

In the French regulatory framework industrial activities are classified according to their hazard potential. Three classes of industrial activities are defined, with for each class specific conditions for obtaining a permit to operate:
- low hazard: a simple declaration at the *Préfecture* is required;
- medium hazard (also called 'A establishments'): a safety report and an environmental impact assessment are compulsory;
- high hazard (also called 'AS' or 'Upper tier Seveso establishments'): a safety report and an environmental impact assessment are compulsory. Land-use planning restrictions are possible.

A safety report also needs to be made for the following constructions and activities:
- dams;
- shunting yards (if more than fifty tank wagons containing hazardous substances are present simultaneously);
- parking areas for tank trucks transporting hazardous substances (if there are more than one hundred parking spaces);
- river ports (more than one million tonnes of goods);
- seaports (more than four million tonnes of goods).

The descriptions of the regulation in force in France which will be presented below concern only upper tier Seveso establishments. Moreover, this report will only deal with the permit to operate process and the land-use planning process. Local emergency plans and public information requirements will not be discussed in detail.

2.1.2 Objectives of the risk assessment

The French regulation introduces the obligation for industrialists to carry out a compulsory risk analysis for each Seveso establishment (upper and lower tier) and to update it every five years.

The risk analysis has to identify all known and possible major accident scenarios, together with their prevention and mitigation barriers. The safety report must be a synthesis of this risk analysis. It has to be specific to the plant considered. This document must present the probability, the kinetic(1) and the possible consequences of each major accident identified in the risk analysis.
The safety report is a technical document. It aims to demonstrate the risk control of the operator. It is a basis for the continuous improvement of the safety in a facility and a tool for the inspection by the authorities.
The results of the safety report are used in the following decision processes:

- the permit to operate and definition of the requirements for risk reduction on site;
- the land-use planning;
- information to the public;
- design of emergency plans.

Probabilities of major accidents and the number of people exposed to their possible consequences are introduced in a risk matrix. This matrix allows the authorities to assess the societal acceptability of the risk generated by a facility in a given environment. If the risk matrix is acceptable, the facility is considered to be compatible with its environment and the authorities will deliver or prolong the permit to operate (see [3]). Figure 2 describes the permit to operate process.

Land-use planning restrictions and land-use modifications may also be applied in the vicinity of existing and future upper tier Seveso establishments ('AS establishments') (see [4]). Effect distances, kinetics and probabilities of dangerous phenomena are used to define areas of high, medium and low risk ('aléa') for thermal, overpressure and toxic consequences. This geographical information is then used for land-use modifications and planning for current and future urbanisation through the 'Plan de Prévention des Risques Technologiques' (Technological Risk Prevention Plan). This plan is usually referred to as 'PPRT'. It aims at mitigating the residual risk, after risk prevention measures at the source have been taken. Zones (based on 'aléa areas') are defined within which requirements can be imposed on existing and future buildings, such as:

- restrictions on future construction and land-use;
- consolidation of existing constructions (example: blast-proof windows)
- expropriation of existing buildings and constructions in the areas exposed to very high 'aléa' levels;
- relinquishment: in areas exposed to high 'aléa' levels, owners could be given the right to force the city (or the local community in charge of land-use planning) to buy their real estate.

Moreover, additional risk reduction measures at the source could be investigated if the costs of these measures balance the real estate costs that are avoided.

[1] See page 26 for an explanation of the term 'kinetic'.

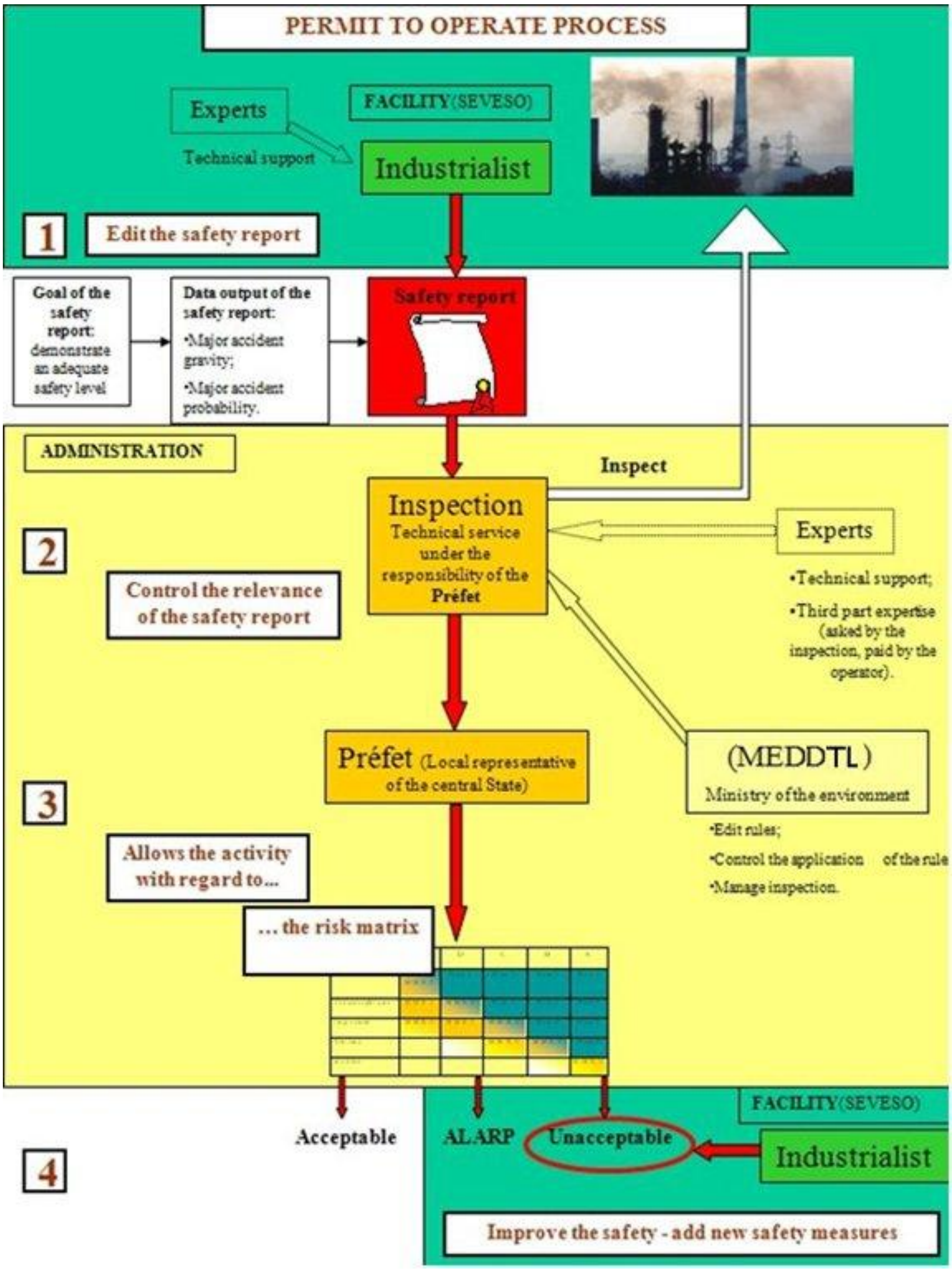

Figure 2 French permit to operate process for a Seveso establishment

Once the PPRT is accepted, it will be implemented in general local urbanisation documents and plans. Figure 3 describes the 'PPRT' process.

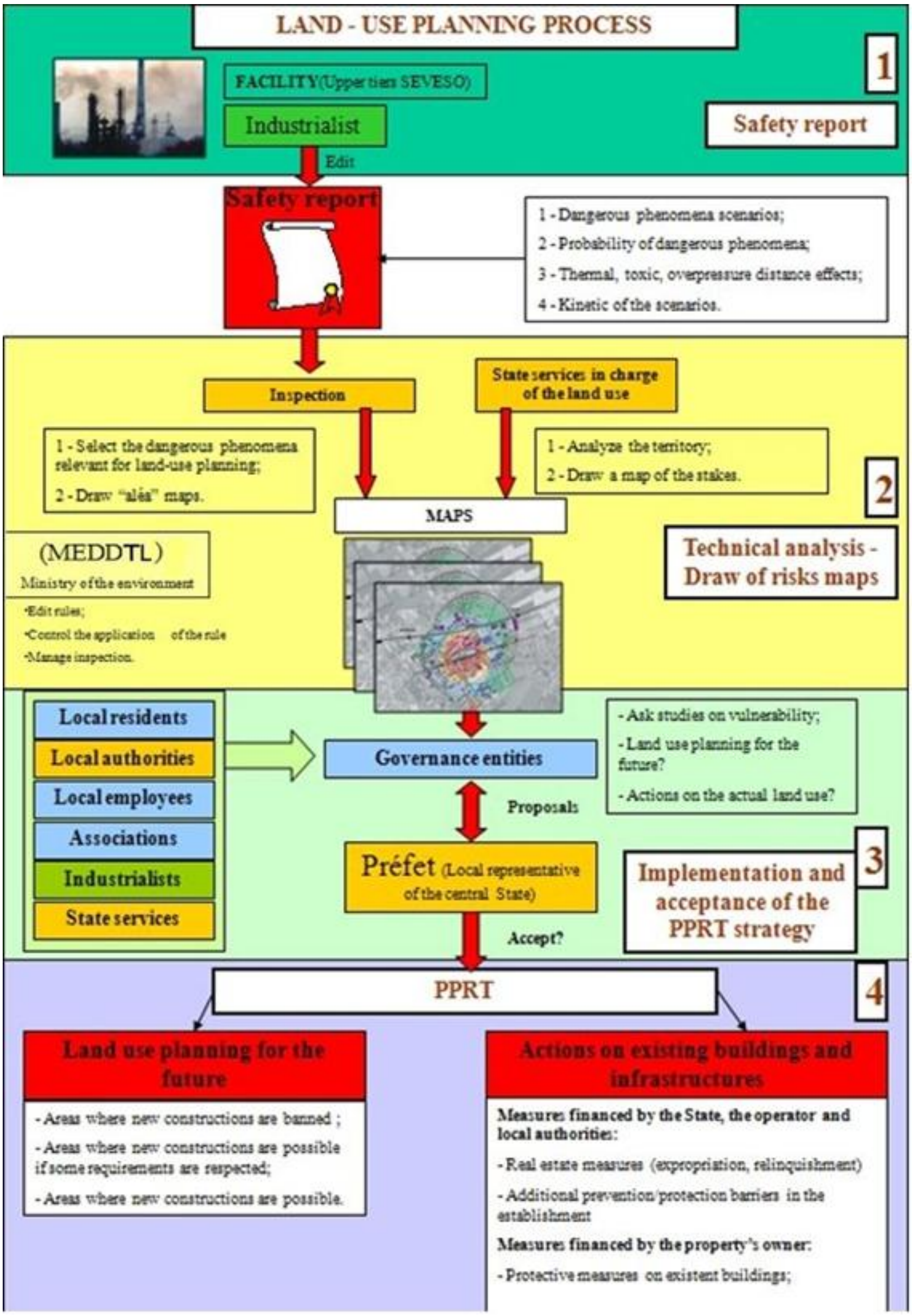

Figure 3 French land-use planning process for upper tiers Seveso establishments

2.1.3 *Acceptance levels*

2.1.3.1 Generalities

Some of the results of the safety reports are used for the two main public decision support tools: the permit to operate process and the land-use planning. These results are the following:

- Concerning the permit to operate:
  - kinetic of major accidents;
  - intensity of major accidents;
  - probabilities of major accidents;
  - severity of major accidents.
- Concerning the land-use planning:
  - kinetic of dangerous phenomena;
  - intensity of dangerous phenomena;
  - probabilities of dangerous phenomena.

Terminology in the French context:

- Accident: Undesirable event such as a discharge of toxic substance, a fire or an explosion which causes consequences and damages on a human being, goods or the environment. The accident is produced by a dangerous phenomenon, when vulnerable targets are exposed to the effects of such a dangerous phenomenon.
- Dangerous phenomenon: Release of energy or substance that may produce damage to vulnerable targets (living beings or objects).
- Effect of a dangerous phenomenon: Characteristics of physical and chemical phenomena linked to dangerous phenomena: thermal radiation, toxic concentration, overpressure and missiles.
- Intensity of the effect of a dangerous phenomenon: Physical measure of dangerous phenomena effects (thermal dose, toxic dose, overpressure level).
- Scenario of a dangerous phenomenon: Event sequence, starting from root causes, that leads to a dangerous phenomenon. Various scenarios may lead to the same dangerous phenomenon. In this case, there are as many scenarios as there are possible event combinations leading to a same dangerous phenomenon. Scenarios studied in the safety report are defined through a risk analysis.
- Central event: Event defined in the risk analysis, usually at the centre of a dangerous phenomenon. This event is often a loss of containment when fluids are studied, and a loss of physical integrity when solids are studied;
- Safety measure: A whole formed by technical and/or organisational elements necessary and sufficient in order to ensure a safety function. The following safety measures may be distinguished:
  - o Prevention measures: these measures aim to prevent the occurrence of a central event or to decrease the probability of a central event;
  - o Mitigation measures: these measures aim to decrease the intensity of the effect of a dangerous phenomenon. When these kinds of safety measures are studied in a risk assessment, both dangerous phenomena resulting from the function and the malfunction of the safety measure have to be considered;

- o Protection measures: these measures aim to limit the consequences of an accident through diminishing the vulnerability of potential targets.

The different scales and definitions that are used in the French regulation framework are explained in the next few paragraphs.

Kinetic of major accidents and dangerous phenomena:
The term 'kinetic' refers to the time scale of the incident and the time needed for evacuating local populations. Fast kinetic phenomena involve dangerous phenomena that may occur rapidly after the beginning of the central event. Examples of fast kinetic phenomena are flash fire, pool fire, tank explosion and vapour cloud explosion. Slow kinetic phenomena are phenomena 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 pressurisation (due to heat impingement).

Intensity of dangerous phenomena:
Four levels are distinguished to classify the intensity of dangerous phenomena:
- significant lethal effect (about 5% probability of fatality);
- lethal effect (about 1% probability of fatality);
- irreversible effect (irreversible health effects);
- indirect effect (e.g. broken windows).

The first three levels are used for both the permit to operate process and the land-use planning process. The latter (indirect) is only used for the land-use planning process.

The end-point values for the intensity of thermal radiation, overpressure and toxic exposure are shown in Table 1.

Table 1 French end-point values for the intensity of thermal radiation, overpressure and toxic effects

Effects	**Level of effects**			
	Significant lethal effect threshold (2)	**Lethal effect threshold (2)**	**Irreversible effect threshold (2)**	**Indirect**
Thermal radiation	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
Toxic exposure	5% lethality	1% lethality	irreversible health effects	

2 The heat radiation levels are used for prolonging fires, heat radiation doses are used for short duration fires, such as fireball and boil-over.

Probability of accidents:
The probability of accidents must be expressed as a range value. These range values are defined in Table 2.

Table 2 Probability classes used in the French regulatory context

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

Severity of major accidents:
In the French regulatory framework, the number of fatalities following a major accident is not calculated. Instead, the severity of accidents is determined from the number of people potentially exposed to certain effects. Five levels are distinguished:
– disastrous;
– catastrophic;
– significant;
– serious;
– moderate.

The severity of a potential accident is derived from the number of persons potentially exposed to thermal radiation effects, overpressure effects or toxic effects of different intensity. For each accident, three intensity thresholds (significant lethal effect, lethal effect and irreversible effect, see previous page) define three different effect envelopes (areas). The severity of a given potential major accident is deduced from the number of persons situated in these areas following a national scale presented in Table 3. If the table is indecisive (for example, if 6 persons reside in the area with lethal effects, and 150 persons in the area with irreversible effects), the highest severity class is used (in this case ‘catastrophic’).
As can be seen from Table 3, the indirect effect is not relevant for the severity classification of a potential accident. It is therefore not relevant for the granting of the permit to operate. The indirect effect is only used for land-use planning in accordance with the PPRT.

Table 3 French scale for the classification of the severity of a potential accident

Number of people potentially exposed			Resulting severity class
Significant lethal effect	Lethal effect	Irreversible effect	
> 10	> 100	> 1000	Disastrous
1 to 10	10 to 100	100 to 1000	Catastrophic
1	1 to 10	10 to 100	Significant
0	1	1 to 10	Serious
0	0	< 1	Moderate

2.1.3.3 Permit to operate

For Seveso establishments, the permit to operate is granted if the facility is considered to be 'compatible with its environment'. The environment means here the area where people may be injured in case of the occurrence of a major accident.

Table 4 is the decision tool used by the French authorities for the assessment of this compatibility.
Each major accident identified in the safety report is assigned a probability range (Table 2) and a severity class (Table 3) and therefore relates to one of the cells in Table 4. Once all identified accidents are characterised with regard to this matrix, the overall acceptability of the matrix, and thereby the overall acceptability of the permit of the facility, is assessed.

Table 4 French risk matrix

Probability class / **Severity**	**E**	**D**	**C**	**B**	**A**
Disastrous		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 consists of three areas:

- an acceptable area (in white): if all identified scenarios are in the acceptable area, the permit to operate is granted (for a new situation) or continued (for an existing situation);
- an unacceptable area (in red): if one or more scenarios are in the unacceptable area, the permit to operate is not granted (for a new situation) or withdrawn (for an existing situation);
- an 'ALARP' (As Low As Reasonably Practicable) area (in yellow): for each accident scenario in this area, continuous improvement of the safety is asked to operators. There are two specific cases among the ALARP areas:
  - the area disastrous/E (upper left box): If an accident scenario is in this area, a distinction is made between new and existing facilities. For a new facility the situation is acceptable if and only if this scenario has at least one barrier, and if this barrier was not considered, the remaining frequency would still be E. For an existing facility, ALARP class 2 conditions apply for the scenarios in this box;
  - ALARP class 2: The total number of accidents in the ALARP 2 boxes of the diagram must be five or lower. If there are more than five accident scenarios, additional technical barriers must be installed in such a way that the amount of ALARP class 2 accident scenarios reduces to five (or

less). More than five ALARP class 2 accidents scenarios are acceptable if and only if:
- all these ALARP class 2 accident scenarios have probability class E;
- all these ALARP class 2 accident scenarios have at least one barrier;
- if this barrier was not considered, the remaining frequency would still be E (for each of these ALARP class 2 accident scenarios).

All other situations with more than five ALARP class 2 accident scenarios are 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.
If the situation is ALARP, the operator must prove in the safety report that all risk reducing measures at an acceptable cost have been implemented.

2.1.3.4 Plan de Prévention des Risques Technologique (PPRT) (Technological Risk Prevention Plan)

The Technological Risk Prevention Plan (PPRT) is relevant for upper tier Seveso facilities ('AS class'). The PPRT is a process which enables the authorities to:
- Use regulation tools for reducing the residual risk. Indeed, even after the reduction of risk at the source through the ALARP process, in some cases, some population can still be exposed to a significant risk. The PPRT gives the authorities a tool for modifying the actual land-use in order to reduce this residual risk.
- Define a land-use plan for the vicinity of a facility which takes into account the risk generated by the facility.

In order to reach these objectives, seven areas with different regimes of risk (aléa levels) are displayed on a map. The regime of risk (aléa level) of a location is determined by the intensity of the phenomena that may occur at the location and the cumulative probability of occurrence. The procedure is as follows:
- define the dangerous phenomena that may occur and their probability classes;
- select the fast kinetic dangerous phenomena, and define the areas with significant lethal effects, lethal effects, irreversible effects and indirect effects related to these fast kinetic phenomena;
- count for each location how many (fast kinetic) dangerous phenomena with significant lethal effects may occur at the considered location, how many phenomena with lethal effects, and so on;
- determine the aléa level for the location using Table 5;
- make an aléa map that shows the aléa level at all relevant locations.

For example, if three different (fast kinetic) dangerous phenomena with probability class E have a significant lethal effect at a certain location, the cumulative frequency for significant lethal effect at this location is 3E. The corresponding aléa level is 'high plus' (H+, see Table 5). If there had been six dangerous phenomena with probability class E and a potential significant effect at this location, the aléa level would have been 'very high' (VH).

If the table is indecisive, the maximum aléa level is used. For example, if a dangerous phenomenon with probability range D has an irreversible effect at a certain location (aléa level 'medium'), and two dangerous phenomena with probability E have a significant lethal effect at the same location (aléa level 'high plus'), the overall aléa level at that location is the maximum of the two, that is 'high plus' (H+).

Table 5 Definition of aléa levels

Maximum intensity of the effect of a phenomenon at a given location	**Significant lethal**			**Lethal**			**Irreversible**			**In-direct**
Cumulative probability of phenomena at a given location	>D	5E to D	<5E	>D	5E to D	<5E	>D	5E to D	<5E	All
	higher < > lower			higher < > lower			higher < > lower			
Aléa level	**VH+**	**VH**	**H+**		**H**	**M+**		**M**	**Low**	

Slow kinetic dangerous phenomena are also considered. However, only the areas impacted by 'irreversible' effects are taken into account. These areas are represented using a specific map.

As soon as the seven aléa areas are laid on the map, together with the surrounding 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 industry, local communities, local associations, local employees, the state, et cetera.

A guidance is given in the 'Guide méthodologique – Le Plan de Prévention des Risques Technologiques (PPRT)' [5] for piloting the definition of the strategy. A part of this guidance is presented in Table 6. Existing constructions can be expropriated or relinquished. In the latter case, people who currently inhabit a house may continue to do so. However, once they move, the house will be pulled down.

Table 6 Guidance for the definition of real estate measures for existing constructions

Aléa level	**Expropriation**	**Relinquishment**
VH+	Automatic for residences. To be defined for other structures.	Automatic.
VH	To be defined.	Automatic for residences. To be defined for other structures.
H+	-	Identical to VH
H	-	To be defined.
M+	-	-
M	-	-
Low	-	-

To summarise, the PPRT introduces the following possibilities for reducing the individual risk:
– expropriation or relinquishment in the higher risk areas;
– additional risk reduction measures in the facility can be investigated if their cost balances the real estate measure cost that is avoided;
– improvements of the population protection through consolidation of buildings and infrastructures.

The cost of these measures is supported by the local communities, the industrialists and the state (for real estate measure and additional risk reduction measures in the facility) or by building and infrastructure owners (if the costs for the works in the building or infrastructure is below 10% of the value of the building/infrastructure).

The PPRT strategy aims to modify actual land-use in the vicinity of a dangerous facility, and also aims to define a land-use plan for new buildings and infrastructures (such as highways and railways). The 'Guide méthodologique' ([5]) also provides guidance for land-use planning issues. A part of this guidance is reproduced in Table 7.
Once approved by the local state representative (Préfet), the PPRT becomes a local land-use planning regulation.

Table 7 Guidance for land-use planning and real estate measures for future constructions

Aléa level	**Restrictions for thermal radiation and toxic effects**	**Restrictions for overpressure effects**
VH+	Ban on new constructions.	Ban on new constructions.
VH	Identical to VH+.	Identical to VH+.
H+	Ban on new constructions but possibility to extend existing industrial buildings and infrastructures if they are protected	Ban on new constructions but possibility to extend existing industrial buildings and infrastructures if they are protected
H	Identical to H+.	Identical to H+.
M+	New constructions possible depending on limitations on use and protective measures.	Protective measures on new buildings.
M	New constructions possible depending on minor limitations on use. Compulsory protective measures for public buildings and industries. No public buildings allow that are difficult to evacuate.	Identical to M+.
Low		New constructions possible depending on minor limitations on use. Compulsory protective measures required for public buildings and industries. No public buildings allowed that are difficult to evacuate.

2.1.4 *Methodology to be used*

As laid out above, the French regulation asks industrialists to carry out a risk analysis. The safety report presented to the administration must summarise this risk analysis and present the probability, the effect distances, the severity and the kinetic of all known possible major accident scenarios, together with their prevention and protection barriers.
Industrialists are free to choose the methodology to be used for the selection of scenarios, the probability assessment and the distance effects calculation, but it is underlined that the safety report must exhaustively take into account all major accident scenarios. Moreover, the relevance of the methodology used has to be justified in the safety report.
Although the choice of the methodologies used in the safety report is passed on to industrialists, guidance is available for some specific issues. For example the following guidance is available:

- The 'circulaire du 10 Mai 2010' (see [6]) gives guidance for writing a safety report (severity calculations, atmospheric dispersion calculations, treatment of specific initial events and dangerous phenomena such as rupture of atmospheric tanks, et cetera).
- Some national working groups have been created. These working groups consist of members from the French ministry, industrialists and experts. These groups deliver guidance on specific issues or on safety reports of one type of facility (events frequencies, effect distance calculation methodologies, et cetera).

The use of these guidelines is not compulsory. However, if these methods are used, their relevance does not need to be justified in the safety report.

2.2 Technical methodology used by INERIS for the current study

This section deals with the methodology used by INERIS in order to perform the risk assessment. The following issues will be presented:

- the methodology used in order to define scenarios and frequencies;
- the ignition probabilities used;
- the consequence and damage criteria.

2.2.1 *Scenarios and frequencies*

2.2.1.1 Scenarios 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, et cetera).
For this aim, a working group will be created. It could, for example, 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, et cetera.
- The consequence 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;
- effectiveness;
- response time adapted to the kinetic of the accident they prevent;
- maintainable;
- testable.

When a mitigation barrier is identified in an accident scenario, both the scenario describing the consequences following the function *and* the malfunction of the safety barrier need to be taken into account.

Please note that the 'qualitative' identification and evaluation process of scenarios and safety barriers is considered by INERIS as an important element of the safety report. In terms of safety, a significant part of the safety report's added value is realised at this stage.

Once the identification process is realised, the scenarios' frequency ranges can be calculated.

2.2.1.2 Scenario frequencies

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

Each root cause frequency is determined by the working group. They are expressed using frequency classes (frequency ranges) (see Table 8).

Table 8 Frequency class table (INERIS)

Frequency class	Failure frequency
F-1	Between 1 and 10 per year
F0	Between 0.1 and 1 per year
F1	Between 0.01 and 0.1 per year
F2	Between 10^{-3} and 10^{-2} per year
Fx	Between $10^{-(x+1)}$ and 10^{-x} per year

Some initial events are not included in scenario frequency calculations such as events related to malevolence, meteorite falls et cetera. Indeed, the French regulation considers that these events can be excluded from frequency calculations if some specific requirements and conditions are fulfilled (see [6]).

In this study, it is assumed that these conditions and requirements are fulfilled. This is represented in bow-tie diagrams as red crosses preventing the sequence of the scenario to continue.

The confidence level of each barrier is also assessed as a probability (reduction) range (see Table 9).

The methodology followed for this assessment is described in the Ω10 and Ω20 guidelines (see [7] and [8]) and is inspired by EN 61508 and EN 61511.

Table 9 Failure probability table for barriers (INERIS)

Confidence level	Failure probability
NC1	Between 0.01 and 0.1 per demand
NC2	Between 10^{-3} and 10^{-2} per demand
NC3	Between 10^{-4} and 10^{-3} per demand

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 classes 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 scenarios, such as leak from the tank or leak from accessories of the tank. Release scenarios are then further combined into central events, such as a pool in the bund or a pool on the roof of a tank. For this grouping the same calculation rules apply as for the grouping of root causes into intermediate events.

With this methodology, the dangerous phenomenon scenarios to be considered, the assessment of the frequency of roots causes and the probability of failure of prevention barriers are specific for each establishment.

An example of a diagram connecting root causes with the central event 'pool in the bund and spray release' is given in Figure 4. In this example, the frequency class for the central event (pool in the bund and spray release) is equal to F2.

2.2.2 *Ignition probabilities*

In the framework of this study, INERIS uses the ignition probability given in [9] and presented in the table below:

Table 10 Ignition probabilities used by INERIS in the current study

Product Location of the cloud	Class B	Class C
Hazardous location (ATEX) area with occasional presence of operators (example: bund)	1×10^{-2}	1×10^{-3}
Hazardous location (ATEX) area with regular presence of operators (example: loading area)	1×10^{-1}	1×10^{-2}
No hazardous location (ATEX) area	1	1×10^{-1}

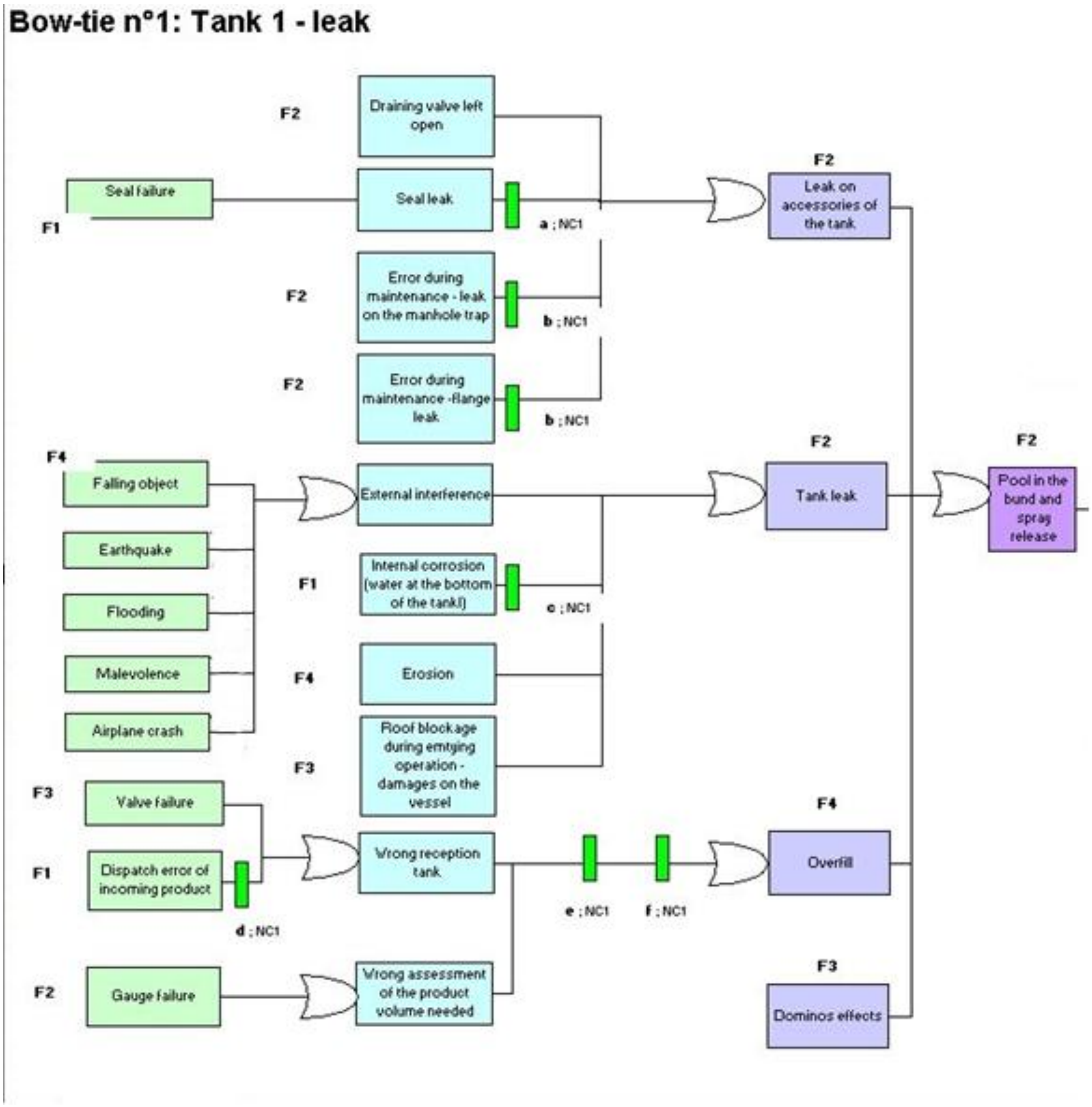

Figure 4 Diagram showing causes and central events for scenario 'Tank leak' according to the methodology used by INERIS

2.2.3 *Consequence and damage criteria*

In the French regulatory context, the potential number of fatalities following the occurrence of a major accident is not a criterion for delivering a permit to operate or for defining the land-use planning. Instead, the decision tools for public authorities are based on the number of persons exposed to three (for thermal radiation effects) or four (for overpressure effects) pre-defined levels of intensity. These levels were discussed in section 2.1.3.1.
Therefore the use of probit functions is not necessary in French safety reports.

For each central event the extent of the hazardous area is determined from the release scenarios lying underneath the central event. For example, for tank 1 the area with a significant lethal effect (see Table 1) for the central event 'pool in the

bund' is the envelop of the areas with 8 kW/m^2 heat radiation or 200 mbar overpressure of the release scenarios 'leak from accessories on the tank', 'leak from the tank', 'overfill' and 'domino effects' (see Figure 4).
If the consequence areas of the release scenarios differ significantly in size (for example if the overfill scenario has a larger consequence distance than the leak from the tank scenario), the grouping of these release scenarios into one single central event will give inaccurate results. For these cases, the methodology allows more detailed diagrams (ungrouping of release scenarios).

2.3 Dutch regulatory context

The Dutch regulatory context is described in Module A of the 'Reference Manual BEVI Risk Assessments' ([10]). A solid framework was established in 2004 when the Decree External Safety for Establishments ('BEVI', [11]) became effective. This decree lays out how third party risk is incorporated in legislation. As third party risk is closely related to industrial activities and land-use, the Decree External Safety for Establishments is linked to the more general Environmental Management Act and Spatial Planning Act. The Decree lists for which groups of industries third party risk needs to be addressed by the competent authority. An official assessment of third party risk by the competent authority is required for the following occasions:
- upon the first effectuation of the Decree for a specific group of industries;
- upon a request for a change in the environmental permit by an industry;
- upon a request for a change in the zoning plan;
- upon a five-year periodic update of the safety report (upper tier Seveso companies only);
- upon a ten-year periodic update of the zoning plan;

The assessment of third party risk by the competent authority comprises two parameters:
- individual risk;
- societal risk.

More details are supplied in section 2.3.2.1 (individual risk) and section 2.3.2.2 (societal risk).

The European Seveso II Directive was implemented in the Netherlands as the Decree on Risks of Major Accidents ('BRZO', [12]) in 1999. In accordance with Seveso II, lower tier companies have to implement a prevention policy for major accidents. Upper tier companies additionally have to write a safety report.
As in France, the safety report must be updated every five years. The safety report has several objectives, such as:
- identification of all major accident scenarios, including causes and possible preventive barriers;
- demonstration that enough effort is made to keep the risks at an acceptable low level;
- overview of the most relevant scenarios for internal emergency plans, external emergency plans and for land-use planning (third party risk assessment).

The safety report needs to be approved by the competent authority (either the local municipality or the regional province). Without a valid and approved safety report, the industry is not allowed to operate. One element of the safety report is the third party risk assessment. For upper tier Seveso companies, it is obligatory to assess the acceptability of third party risk using the outcomes of a Quantitative Risk Analysis (QRA). A new QRA is made every five years when the safety report is updated. The relation between the QRA and the land-use around the facility is set down in the Decree External Safety for Establishments ('BEVI', see above).

2.3.1 *Scope of regulations (which types of industries?)*

The types of industries for which third party risk needs to be addressed are listed in the 'Decree External Safety for Establishments' ('BEVI', [11]). The current list comprises the following types of industries:

a. Seveso companies (upper tier and lower tier).
b. Train marshalling yards (marshalling of hazardous goods).
c. LPG filling stations.
d. Storage facilities for hazardous goods (10,000 kg or more).
e. Industries with one or more ammonia freezing units (1500 kg or more).
f. Specific groups of industries, i.e. industries with installations containing 1500 kg or more of ammonia (with the exemption of freezing units), industries with 150 m^3 or more (highly) flammable liquids in an aboveground storage vessel, industries with equipment containing 13 m^3 or more of propane or acetylene, industries using a cyanide solution of 100 l or more for electroplating, industries with equipment containing 1000 l or more of (very) toxic substances, industries with gas cylinders containing (in sum) 1500 l or more of (very) toxic substances, and establishments where gas from the national grid is reduced in pressure.
g. Other industries that require an environmental permit and produce an individual risk higher than 10^{-6} per year on any location outside the site boundary.

Generic distances for third party risk are defined for most of the above categories. Calculations are carried out for upper tier Seveso companies and some specific cases.

2.3.2 *Objectives of the risk assessment (including acceptance levels)*

The primary objective of a risk assessment is to see if the risk posed by an industry is acceptable for the society. In the Dutch legislative context, the acceptability is assessed using two parameters: individual risk and societal risk. These indicators are calculated by the operators with a Quantitative Risk Analysis (QRA). For Seveso companies, it further needs to be identified which major accident scenarios may occur and if the company has taken sufficient measures to reduce the risk corresponding to these accident scenarios. This objective is met by inspection of the safety management system, which is described in the prevention plan (lower tier Seveso facilities) or the safety report (upper tier Seveso facilities).

2.3.2.1 Individual risk

The first parameter that is used to determine the acceptability of the presence of a company in relation to its surroundings, is the Individual Risk contour of 10^{-6} per year (hereafter IR 10^{-6} contour). A distinction is made between 'vulnerable objects' and 'objects of limited vulnerability'. Vulnerable objects include among others houses in non-rural areas, schools, elderly homes, child day-care facilities, camping sites and recreational facilities with accommodation for fifty or more visitors, and large office buildings, hotels and shopping centres. Objects of limited vulnerability include among others houses in rural areas (no more than two houses per hectare) and office buildings, shopping centres and recreational facilities with limited numbers of people present. A further distinction is made between existing situations and new situations. Existing situations refer to industries with a permit in force and current and future land-use that is in accordance with an approved zoning plan of the competent authorities. New situations refer to modifications of the environmental permit or modifications of the zoning plan.

- For existing situations, no vulnerable objects are accepted in the area where the individual risk exceeds 10^{-6} per year. Problematic cases have to be resolved within terms defined in the Decree. This may either involve actions at the source (additional safety measures) or actions in the surroundings (removal of vulnerable objects). State funding is available for resolving urgent situations. Objects of limited vulnerability are undesirable in the area where the individual risk exceeds 10^{-6} per year. If objects of limited vulnerability are present within the IR 10^{-6} contour, significant effort should be made to improve the situation. As there is no formal obligation to resolve the situation, this process will typically involve a debate between the operator and the competent authority on which additional safety provisions are reasonable and who will pay for it. If no agreement can be reached on additional safety measures at the source, safety measures at the target (people in the surroundings) sometimes provide a solution. An example of the latter is improved accessibility of the area for emergency response units and improvement of the means for people to reach a safe situation (early warning, shelter facilities, frequent training, et cetera).
- New situations cannot be approved if vulnerable objects are present in the area where the individual risk exceeds 10^{-6} per year (or if the zoning scheme allows vulnerable objects in this area). New situations where objects of limited vulnerability are present within the IR 10^{-6} contour, are highly undesirable and need to be accounted for and approved by the council of the competent authority.

2.3.2.2 Societal risk

The second parameter that is used to determine the acceptability of the presence of a company in relation to its surroundings is societal risk. Societal risk is assessed when industries desire a change in the environmental permit or when authorities desire a change in the zoning scheme for land-use. This assessment is referred to as 'the duty to account for the societal risk' ([13]) and involves a process in which stakeholders discuss the benefits of the development, the consequences for the society and options for risk reduction.

The stakeholders include:

- the permit-holder;
- the competent authority, including the city council, the fire brigade, the land-use office and the environment office;
- nearby industries which also handle, store or transport hazardous substances;
- representatives from the public (people that work or live near the facility);
- if relevant, real estate developers.

The assessment (account) of societal risk involves a comparison of at least three options:

1. The current situation.
2. The proposed new situation.
3. One or more alternatives to the proposed development that include additional risk mitigation measures. These alternatives may involve additional technical or organizational measures at the source, technical or organizational measures in the surroundings, relocation of the hazardous activity and modification of the development plan (building in a different way or at a different location).

The comparison is based on the following elements:

- the height of societal risk in relation to 'guide values'[3];
- the increase of societal risk (for the proposed new situation and the alternatives);
- the possibilities for people to self-rescue;
- the possibilities for relief by emergency response units;
- the benefits and necessity of the development;
- the hazards for disruption of the economy and/or society;
- the amount of non-lethal injuries in an accident;
- the amount of delayed fatalities in an accident.

Based on these elements, the city council must decide which option is preferred: the current situation, the proposed new development or one of the alternatives to the proposed new development. This decision must be both official and transparent. In particular, a council has the freedom to accept an option with a societal risk above the guide values and the freedom to decline an option with a risk below the guide values, as long as a thorough account of benefits and harms is made.

The duty to account for the societal risk is relatively new in the Netherlands. A guideline ([13]) was only published in November 2007. In 2010, an evaluation was carried out to see if it was indeed put to practice as desired ([14]). The main outcomes of this evaluation were:

- the objective of the account of societal risk is not fully understood by all parties; the account is just one of various decision making processes, it is not clear to everyone what should be achieved specifically with the account of societal risk;
- the duty to account for the societal risk is generally not associated with a high priority; because of its 'invisibility' third party risk does not receive a lot of attention in general and societal risk is associated with a (even) lower sense of urgency than individual risk;
- the timing of the account of societal risk is such that it is not an efficient process for further improvement of safety; the account usually takes place at the end of the time-line (when all required data are available) but at this time, changes in the design are no longer feasible.

[3] The following guide values apply to establishments: the guide value for an accident with 10 or more lethal victims is 10^{-5} per year, the guide value for an accident with 100 or more lethal victims is 10^{-7} per year and the guide value for an accident with 1000 or more lethal victims is 10^{-9} per year.

The evaluation also showed that in general there was support for the idea to carry out an account for societal risk. With some additional tools and some modifications in the process, the impact of the account could be increased.

2.3.2.3 Safety report

The upper tier Seveso companies have to write a safety report. This safety report has to identify all known and possible major accidents scenarios, together with their prevention and mitigation barriers. The safety report is, at first, a technical document. It aims to be a basis for the operator's implementation of safety improvements and a tool for authorities' inspections. The quantitative risk assessment (QRA) is part of the safety report. The spatial outcomes of the QRA need to be implemented in the zoning schemes of the competent authorities. These spatial outcomes comprise the IR 10^{-6} contour and the maximum consequence distance. Within the IR 10^{-6} contour, new developments are subject to serious restrictions (see section 2.3.2.1). The maximum consequence distance is relevant for societal risk. This comprises the area where new developments need to be accounted for by the competent authorities (see section 2.3.2.2).

Figure 5 describes the assessment of the safety report and the effectuation in the land-use planning:

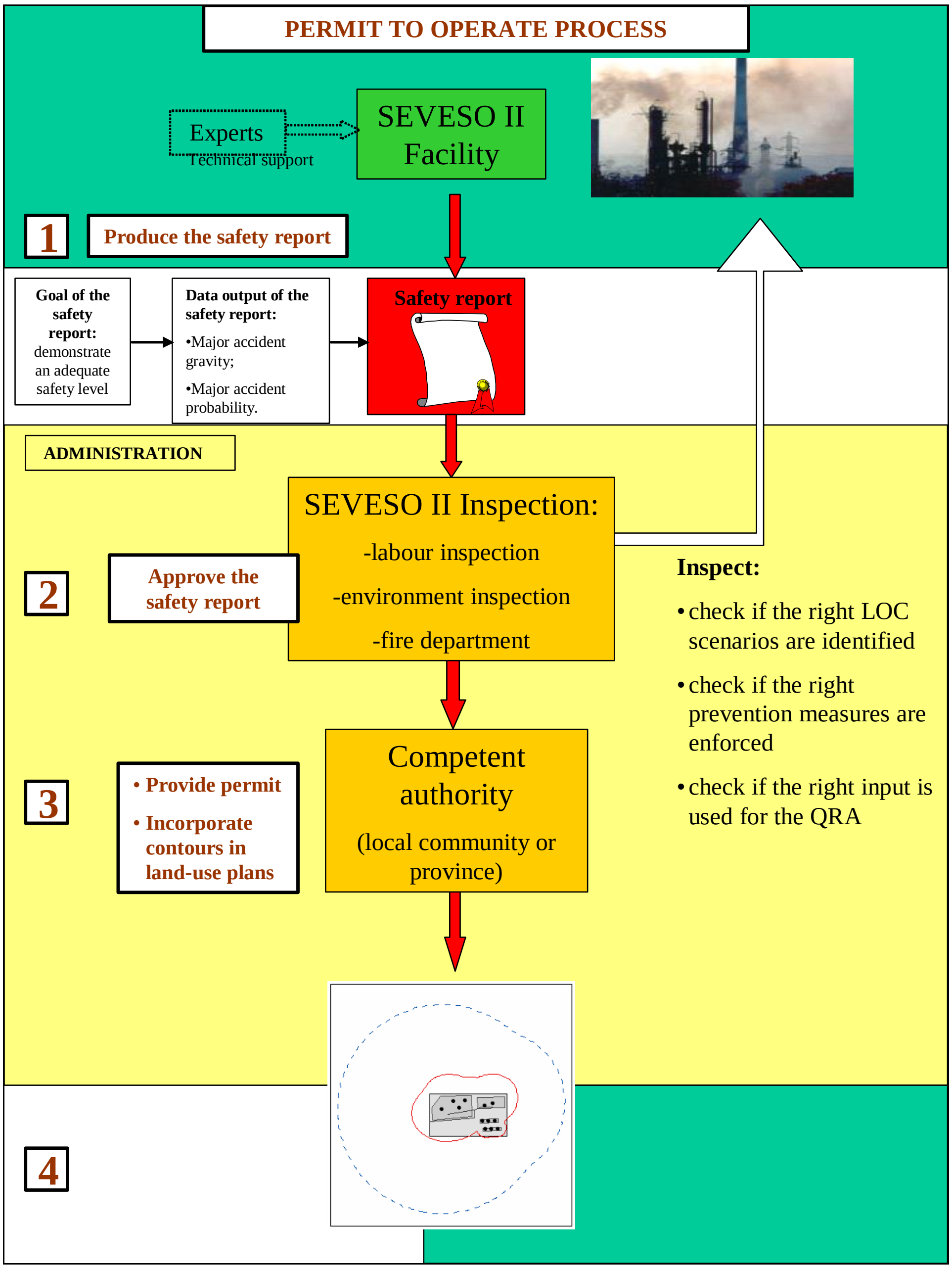

Figure 5 *Assessment of the safety report and effectuation in permitting and land-use planning*

2.3.3 *Methodology to be used*

Prior to 2006, there were no formal requirements for the methodology to be used. The applicability of the method used was to be determined by the competent authority. In most risk assessments a reference was made to the 'coloured books'. This provided some common ground for risk assessments, but differences occurred as a result of missing information in the coloured books and the use of different software tools.

In order to determine to which extent risk outcomes differed, a benchmark study was carried out. This benchmark involved a hypothetical establishment with various installations typical for Seveso companies. Individual and societal risks were calculated by five different risk consultancy companies. The results of this benchmark were published in 2001 [15]. It turned out that the outcomes for individual and societal risk differed at least one order of magnitude [16]. As this result was undesirable in the light of the legal consequences of risk calculations, the former Dutch Ministry of VROM started an initiative to further unify risk calculations. This initiative resulted in the prescription in the BEVI decree [11] to use a specific methodology (Reference Manual BEVI Risk Assessments, [10]) and a specific software tool (SAFETI-NL). The consequence of the legal framework is that the methodology is quite generic and does not always account for the local situation. If this leads to an undesired situation (e.g. an intolerable outcome that is not regarded as realistic), the legislation does allow deviation from the methodology:

- minor deviations from the methodology are possible if and only if approved by the competent authority;
- major deviations from the methodology are possible if and only if approved by the minister.

Examples of minor deviations are the use of different scenario frequencies, different release heights and different release durations. As said, these deviations need to be justified and approved by the competent authority. Examples of major deviations are the use of different scenarios and different consequence models. These types of deviations are fundamental, may affect the 'level playing field' and therefore require approval from the minister.

2.4 Dutch technical methodology

2.4.1 Scenarios and frequencies

The scenarios to be used for QRA calculations for installations in the Netherlands are described in the 'Reference Manual BEVI Risk Assessments' [10]. This reference provides a complete list of central events that must be taken into account and their associated failure frequencies. Many of these frequencies have been derived in early, influential QRA studies, such as [17]. Several attempts have been made to update the failure frequencies since, but so far with limited success.

For atmospheric storage tanks three scenarios need to be considered, namely the catastrophic rupture of the tank, the release of the entire contents in 10 minutes and a leak from a hole with a diameter of 10 mm (see Table 11). The failure frequencies to be used for single containment atmospheric storage tanks were derived from the failure frequencies of pressurised storage tanks. The probability of a significant release from a pressurised storage tank was derived at 1×10^{-6} per year. As it was doubted whether the catastrophic rupture was sufficiently conservative for a 'significant release' in general, it was decided to use two release scenarios: an instantaneous release of the full contents with a frequency of 5×10^{-7} per year and a continuous release of the full contents in 10 minutes, also with a frequency of 5×10^{-7} per year. Subsequently, the failure frequency for atmospheric tanks was estimated to be 10 times higher (5×10^{-6} per year for the instantaneous release and 5×10^{-6} per year for the release in 10 minutes). The failure frequency for a small leak (diameter 10 mm) was estimated to be 10 times higher than the frequency of a big leak ($5\times10^{-6} + 5\times10^{-6} = 1\times10^{-5}$), giving a value of 1×10^{-4} per year for a leak from an atmospheric tank ([18]).

The release scenarios were re-evaluated in 2006-2007 ([19]). For atmospheric storage tanks, the instantaneous release scenario is currently regarded to be representative for a bottom collapse of the tank or a zip rupture of the tank. These events predominantly produce an evaporating liquid pool. The possibility of bund overtopping is taken into account by setting the pool size to 150% of the total bund area.
The release of the entire contents in 10 minutes is considered to be representative for (very) large continuous releases, for example overfilling or a release from the largest connection to the tank with possible escalation (increasing hole size).
The release from a hole with a diameter of 10 mm is representative for small leaks, such as corrosion leaks and leaks from drains and flanges.

Table 11 Scenarios for single containment atmospheric storage tanks (RIVM)

Scenario	**Frequency**
Instantaneous release of entire contents	5×10^{-6} per year per tank
Release of entire contents in 10 minutes in a continuous and constant stream	5×10^{-6} per year per tank
Continuous release from a hole with an effective diameter of 10 mm	1×10^{-4} per year per tank

For transfer of fuel in the loading area, rupture and leak of the loading arm are considered. The frequencies to be used for transfer by loading arms were derived in the early 1980s ([17]). The information on the contribution of various root causes to each of these frequencies is limited (see [10] and [18] for further information).

Table 12 Scenarios for transfer of chemicals to/from tank trucks (RIVM)

Scenario	**Frequency**
Rupture of the loading arm (full bore rupture)	3×10^{-8} per hour
Leak from the loading arm (hole diameter 10% of pipe diameter)	3×10^{-7} per hour
Rupture of the tank truck	1×10^{-5} per year
Leak from the tank truck (largest connection)	5×10^{-7} per year
Fire under tank: instantaneous release of the inventory of a tank truck resulting in a pool fire	5.8×10^{-9} per hour

Regarding pumps, leak and rupture of the pump are considered. The frequencies to be used for centrifugal pumps were adopted from [20]. The contribution of various root causes to each of these frequencies is unknown.

For pipelines, rupture of the pipe and leak from the pipe are considered. The frequencies to be used for a 12″ pipeline ([10]) are taken from various earlier sources including [17]. The frequencies were recently compared to CONCAWE data

([21])[4]. The most frequent cause for pipeline rupture is external damage by third parties.

Table 13 Scenarios for pumps (RIVM)

Scenario	Frequency
Rupture of the pump (rupture of the supply pipe)	1×10^{-4} per year
Leak from the pump (leak with a diameter of 10% of supply pipe diameter)	4.4×10^{-3} per year

Table 14 Scenarios for pipelines (diameter 150 mm or more) (RIVM)

Scenario	Frequency
Rupture of the pipe (full bore rupture)	1×10^{-7} per meter per year
Leak from the pipe (hole size 1.2” diameter)	5×10^{-7} per meter per year

2.4.2 *Ignition probabilities and event types*

As discussed in section 2.4.1, RIVM uses loss of containment scenarios as central events. For flammable liquids, both direct ignition and delayed ignition are considered. The probability of direct ignition to be used in a QRA is prescribed by the guideline ([10]) and depends on the volatility of the liquid (see Table 15). If a release is not ignited immediately, delayed ignition can occur if the flammable cloud meets an ignition source. For individual risk it is assumed that the flammable cloud will always ignite if it crosses the site boundary. For the calculation of societal risk, ignition depends on the presence of ignition sources both on site and off site[5]. See appendix 4A of part 1 of ‘the purple book’ ([18]) for further information including prescribed ignition probabilities. Delayed ignition is not considered to be relevant for class 2 and class 3 flammable liquids.

For releases of (atmospheric or pressurised) liquids, SAFETI-NL calculates evaporation prior to rainout as well as evaporation after rainout (see Figure 6). As a result of the vapours and aerosols produced prior to rainout, direct ignition not only results in an ‘early pool’ fire but also in fireball effects (in case of an instantaneous release, see Figure 7) or jet fire effects (in case of a continuous release, see Figure 8). However, these fireball and jet fire effects will usually be negligible, especially for releases of class 2 flammable liquids.

4 In the light of this comparison, RIVM proposed to update the frequency for rupture to 1.5×10^{-7} per meter per year and the frequency for leak to 5.8×10^{-7} per meter per year. As this proposal has not yet been affected, the ‘old’ values from the reference manual are used for the current analysis. The impact of using the ‘new’ values will be minimal.

5 The calculation for individual risk presumes that a flammable cloud always ignites if it crosses the site boundary. This calculation is more conservative than the calculation for societal risk, which considers actual ignition sources present off site. The reason is that individual risk contours are used for the planning of future spatial developments and therefore needs to be conservative with respect to ignition probabilities. The calculated societal risk represents the current situation and therefore should be realistic.

Table 15 Probability of direct and delayed ignition for atmospheric liquids

Type of (flammable) liquid	Probability of direct ignition	Probability of delayed ignition
Class 1 liquid [a]	0.065	maximum 0.935
Class 2 liquid [b]	0.01 [d]	0
Class 3 liquid [c]	0 [d]	0

(a) Flash point between 0° and 21° (see Vocabulary).
(b) Flash point between 21° and 55° (see Vocabulary).
(c) Flash point between 55° and 100° (see Vocabulary).
(d) A different probability of direct ignition applies when the temperature of the liquid exceeds the flash point (see Note 2 in section 3.4.6.6 of [10]).

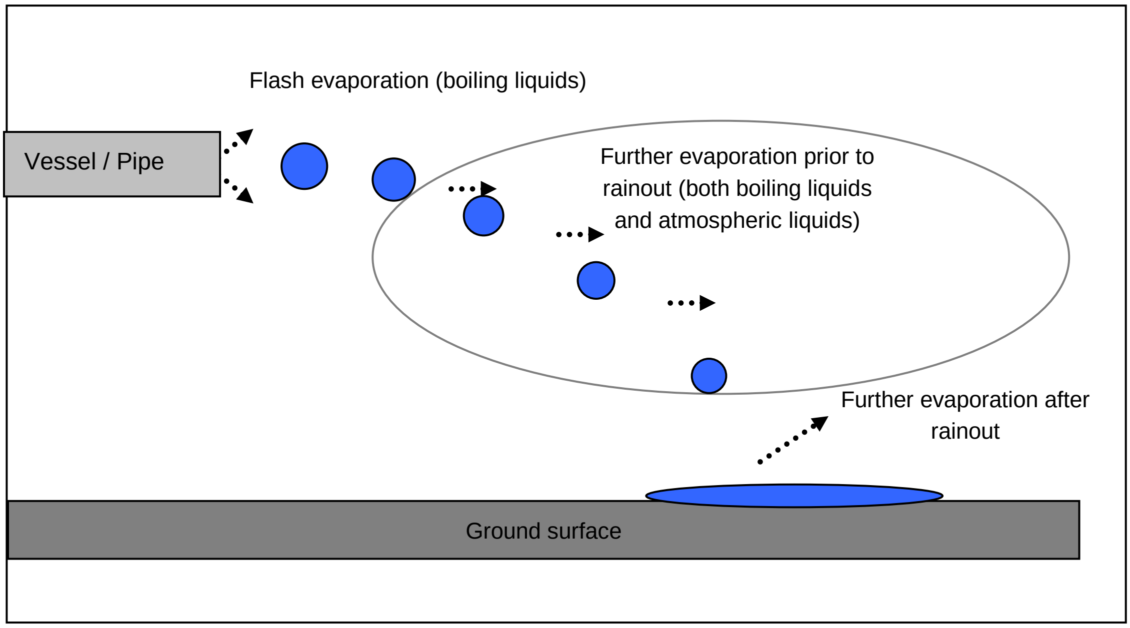

Figure 6 Formation of a vapour cloud in SAFETI-NL

As can be seen from Table 15, delayed ignition is only considered for releases of class 1 flammable liquids. In many cases the vapour cloud will not reach further than the pool. A large vapour cloud will only occur if the evaporation prior to rainout is high. This may either be when the release height is high or when the hydrostatic pressure in a vessel is significant. It will be observed in section 4.2.2.3 that delayed ignition of the vapour cloud is very relevant for the ten minute release scenarios and is hardly relevant for all other scenarios.

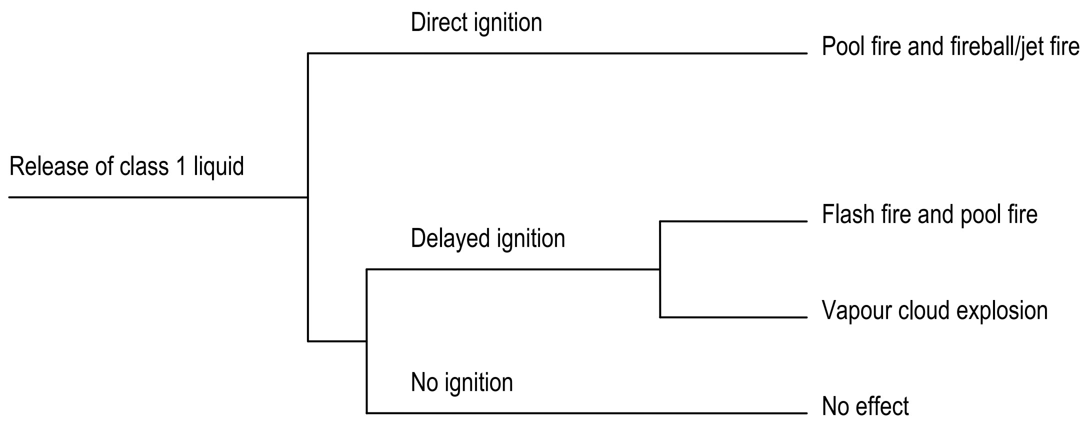

Figure 7 Event tree for dangerous phenomena following a release of class 1 flammable liquids

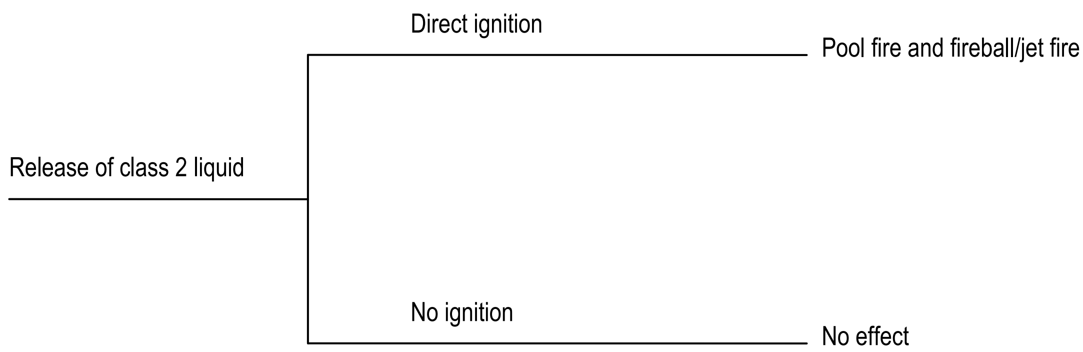

Figure 8 Event tree for dangerous phenomena following a release of class 2 flammable liquids

2.4.3 *Consequence and damage criteria*

If the considered consequence is a fire, the lethality is derived from Table 16. The probit for heat radiation is a function of heat radiation intensity and exposure duration[(6)]. For ongoing fires, such as pool fires and jet fires, a maximum exposure duration of 20 s is used for the derivation of probit and lethality. The assumption is that people outside the flame envelope and 35 kW/m^2 contour, will be able to escape within 20 s. If the release duration is 20 s or longer, the radiation level of 9.85 kW/m^2 corresponds to 1% lethality. As the exposure duration used for risk analysis never exceeds 20 s, radiation levels below 9.85 kW/m^2 are irrelevant for the QRA.

As can be seen from Table 16, the calculation of individual risk is more conservative than the calculation of societal risk. For societal risk the protective effect of walls and windows is taken into account if the heat radiation is below

35 kW/m^2. For people outdoors, the protective effect of clothing is considered in the societal risk calculation but not in the individual risk calculation.

Table 16 Consequence for heat radiation (RIVM method)

Area	**Probability of fatality for individual risk**	**Probability of fatality for societal risk (people indoors)**	**Probability of fatality for societal risk (people outdoors)**
Within flame envelope	1	1	1
Heat radiation > 35 kW/m^2	1	1	1
Heat radiation < 35 kW/m^2	probit (6)	0	0.14 * probit (6)

If the considered consequence is an explosion, the lethality is derived from Table 17. For more information, see sections 3.4.9.2 and 3.4.9.3 of [10].

Table 17 Consequences of overpressure (RIVM method)

Area	**Probability of fatality for individual risk**	**Probability of fatality for societal risk (people indoors)**	**Probability of fatality for societal risk (people outdoors)**
Overpressure ≥ 0.3 bar	1	1	1
0.1 bar ≤ overpressure < 0.3 bar	0	0.025	0
Overpressure < 0.1 bar	0	0	0

The number of people present in the vicinity of the industry should be modelled as realistic as possible. For this area, a detailed study needs to be carried out by the risk analyst. If necessary, the competent authority can be asked to supply more detail. At further distance, generic data for houses, offices and other population objects can be used. From 2010 onwards, a GIS download application will be available to further facilitate population data input for societal risk calculations. Further details are supplied in a national guideline for societal risk calculations ([13]).

2.5 Summary and conclusions

The French and Dutch regulatory frameworks and methodologies of risk assessments have both been designed in order to comply with the same European directive: the Seveso II Directive. However it is observed that these frameworks and methodologies are very different.
A first difference involves the use of the risk results. In France, these results can be used both for the process for the permit to operate and the land-use planning process. In Netherlands, risk results can be used for land-use planning at all times,

6 The probit equals -36.38 + 2.56 ln ($\int Q^{4/3}\,dt$), with heat radiation (Q) in W/m^2 and exposure time t in s.

but can only be used for permitting reasons if there is a (new) request for a permit or a request to change the permit (i.e. a change in activities).
Moreover, while both France and the Netherlands use the concept of individual risk and societal risk, the indicators of these are different:

- Netherlands: iso-curves of the probability of death of 10^{-6} per year for individual risk (land-use planning) and FN-curve for societal risk are considered. Relatively strict rules apply to individual risk, as vulnerable objects are not tolerated inside the 10^{-6} contour and objects of limited vulnerability are highly undesirable inside this contour. No strict rules are defined for societal risk, thereby intentionally allowing specific consideration of the acceptable societal risk level at a local level;
- France: ‘aléa’ areas for individual risk (land-use planning) and a risk matrix for societal risk (permit to operate) are used. The results related to these indicators both have well-defined regulatory consequences.

Also, the technical data used in order to determine these indicators are different:

- End-points values: in France, pre-defined effect distance thresholds have been defined by the ministry for thermal, overpressure and toxic effects. These thresholds represent the limits for significant lethal effects (5% probability of fatality), lethal effects (1% probability of fatality), irreversible effects on the human life and indirect effects (windows broken). In safety reports, effect distances are given with regard to these thresholds. In the Netherlands, probit functions are used in order to relate the level of intensity of an effect to the probability of death of a human. More particularly, non-lethal effects are not taken into account for current and future land-use in the Netherlands.
- Severity and probability: both methodologies use the severity and the probability (or frequency) of dangerous phenomena in the risk assessment. However, these two quantities are expressed as values (real numbers) in the Netherlands and as range values in France.
- Kinetic of the dangerous phenomena: slow kinetic dangerous phenomena are studied in France whereas in Netherlands they are not: if such a scenario would happen, it is considered that the population would be able to evacuate before effects affect areas outside the establishment.

Finally the methodologies used in order to obtain these technical data are not similar. In Netherlands, the methodology to be used is prescribed, including the loss of containment scenarios, frequencies, event trees for consequences, ignition probabilities, meteorological data and consequence models. In France, operators are free to choose their preferred methodology in order to define these data. The relevance of this choice has to be justified in the safety report. Guidance is provided by technical working groups for specific type of facilities and by the French ministry of environment. In the framework of this study, the choices of the INERIS have been based on guidelines edited by the relevant French ministry or by the national working group on storage of flammable liquids. Other choices have been based on the experience and tools developed by INERIS in order to realize safety reports. In particular, the central event frequencies are derived in this study from initial event frequencies and levels of confidence for prevention barriers through bow-tie diagrams. Many of the consequences models have also been developed by INERIS.

In general, the same stakeholders are involved in the public decision-making process related to the risk of Seveso establishments. Two differences may be noticed:

- In the Netherlands, the official decision is made by the executive body of the competent authority. This executive body is elected by the council of the competent authority. In France, this decision is made by the head of a local authority (at a regional level). This person is a direct representative of the state.
- In France, the decision-making process related to land-use planning is designed in order to involve a larger number of stakeholders (for example local populations and associations). In the Netherlands, the decision-making process is primarily an interaction between the competent authority and the industry involved. Other stakeholders will get involved if the zoning plan needs to be altered.

As seen above there are significant differences between the Dutch and the French approaches. These differences make the benchmark exercise complex since most of the results of the study will not be fully comparable.

3 Description of the depot

In order to realise this study, a fictitious oil depot was defined, including (imaginary) surroundings. This installation is presented below with all data required to carry out the risk assessment.

3.1 Generalities

The facility considered here is a storage depot for flammable liquids composed of seven tanks in two bunds. The product is transported to the depot using a pipeline. The product is stored and transferred to tank trucks.

The figure below presents a map of the depot:

- Bund A is the larger bund and contains a 40,000 m^3 floating roof crude oil tank (tank 1) and three 12,500 m^3 fixed roof Jet A tanks (2, 3 and 4).
- Bund B is a smaller bund and contains a 12,600 m^3 floating roof gasoline tank (tank 5), a 1250 m^3 internal floating roof gasoline tank (tank 6) and a 1250 m^3 fixed roof domestic fuel tank (tank 7).
- A pipeline enters the site from the west (the left of the picture) and splits into two parts near the bunds. Another pipeline of the same dimension connects the storage tanks with the pump and loading areas.
- Tank cars can be stationed in the southern part of the facility. This part is conceived to be a 'congested area'.

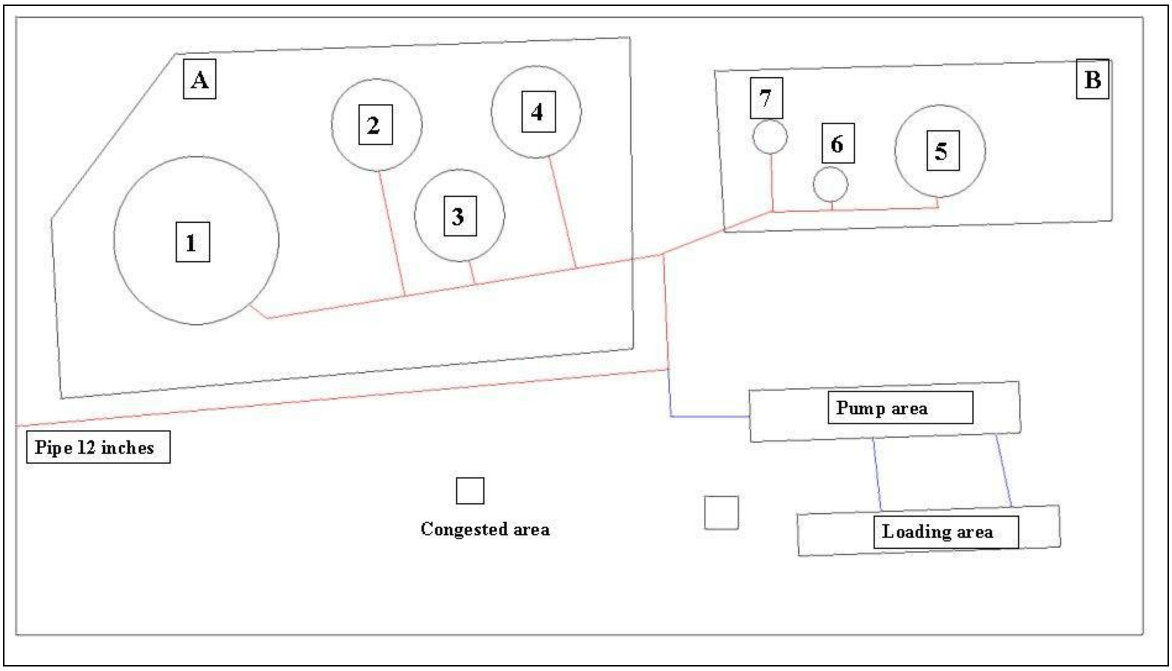

Figure 9 Layout of the flammable liquid depot

Further details:

- The size of the establishment is 400 m long and 218 m wide.
- We assume the establishment lays on a completely flat area.

- The distance between the establishment and the nearest airport is more than 2 km.
- The establishment is in compliance with the «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» (repealed by the text of the 'circulaire du 10 Mai 2010'', see [6]) concerning earthquake, flooding, direct effects of a lighting strike, snow and wind.
- Products handled in this facility are presented in Table 18.

Table 18 Products handled in the facility

Product name	**Density (kg/m^3)**	**Flash point**	**LFL - UFL[(a)] (% vol.)**	**Self-ignition temperature**
Jet A1	From 775 to 840	≥ 38 °C	0,7% - 5%	> 230 °C
Domestic fuel oil (DFO)	From 830 to 880	> 55 °C	0,5% - 5%	> 250 °C
Gasoline (SP 95 and SP 98)	From 720 to 775	< -40 °C	1% - 8%	> 300 °C
Crude oil	Not available	< -20 °C	Not available	280 °C

(a) LFL: Lower Flammability Limit, UFL: Upper Flammability Limit.

Table 19 presents the classification of these products with regard to the French and the Dutch regulations.

Table 19 French and Dutch product classification

Product	**Dutch classif.**	**Definition**	**French classif. (ICPE)**	**Definition**
Gasoline	Class 1	Seveso II, Annex I, part 2, category 7 a/b: flash point between 0 and 21 °C	B	Flash point < 55 °C and $P_{sat\,|\,35°C}$ < 100kPa
Crude oil				
Jet A1	Class 2	Seveso II, Annex I, part 2, category 6: flash point between 21 and 55 °C		
DFO	Class 3	flash point between 55 and 100 °C	C	55 °C ≤ Flash point ≤ 100 °C

According to Dutch legislation, gasoline and crude oil are both classified as flammable liquids of class 1. Jet fuel is a class 2 flammable liquid and domestic fuel oil is a class 3 flammable liquid. See Vocabulary for definitions. The risk of the storage of the class 3 flammable liquids is considered to be irrelevant. In the INERIS approach, gasoline, crude oil and jet fuel are all class B flammable liquids and domestic fuel oil is class C. All products are considered in the risk analysis.

3.2 Storage

General information on bund A and bund B is given in Table 20. The required information for the storage tanks is shown in Table 21.

Table 20 Description of the bunds

	Bund A (Tanks 1, 2, 3, 4)	**Bund B (Tanks 5, 6, 7)**
Maximum volume of product	80,000 m^3	14,385 m^3
Bund surface	22,290 m^2	7370 m^2

Table 21 Description of the storage tanks

	Tank 1	**Tank 2,3,4**	**Tank 5**	**Tank 6**	**Tank 7**
Product	Crude oil	Jet A1	Gasoline (SP 95)	Gasoline (SP 98)	DFO
Diameter	60 m	33 m	33 m	12.5 m	12.5 m
Height	22 m	18 m	18 m	13 m	13 m
Containment	Single containm.	Single containm.	Single containm.	Single containm.	Single containm.
Roof	Floating roof	Fixed roof	Floating roof	Internal floating roof	Fixed roof
Max volume used	40,000 m^3	14,500 m^3	12,600 m^3	1250 m^3	1250 m^3
Max height of the product	14.1 m	16.9 m	14.7 m	10.1 m	10.1 m
Total volume in the tank	62,204 m^3	15,395 m^3	15,395 m^3	1595 m^3	1595 m^3
Design pressure	N/A	below 25 mbar	N/A	below 25 mbar	below 25 mbar

3.3 Loading area and pump area

The required information for the pump area is shown in Table 22. The required information for the loading area is shown in Table 23.

Table 22 Description of the pump area

Pumps:	
Number	7
Type	Centrifugal not canned
Flow rate	120 m^3/h
Pipes:	
Input pipe:	length: 44m, diameter 5 inch
Output pipe diameter	2 racks, length 26,2 m each pipe, diameter 4 inch each pipe
Bund:	
Surface	1728 m^2
Closing valves:	
Location	100 m maximum distance from pumps
Response time (detection of high concentration and closing of valves)	2 minutes

Table 23 Description of the loading area

Generalities:	
Number of loads	100 per day
Volume of product loaded	1,000,000 m^3/y
Tank trucks:	
Tank trucks size	36 m^3
Tank truck maximum content	90%
Max height of product in the tank truck	2.1 m
Compartmentalised	No
Presence class 1 tank truck	9640 h/y
Presence class 2 tank truck	7601 h/y
Presence class 3 tank truck	225 h/y
Loading procedure:	
Equipment	Loading arm 4 inch internal diameter
Loading arm flow rate	120 m^3/h
Pressure	3 bar
Location of the closing valve	Between 5 m and 35 m
Emergency stop (response time)	30 s
Products:	
1 DFO loading post (loading from the top)	450 loads /y
6 multi product loading post (loading from the bottom)	34,550 loads /y (44% jet A1, 56% gasoline and crude oil)
Time transfer of class 1 flammable liquids	5224 hours /y
Time transfer of class 2 flammable liquid	4105 hours /y
Time transfer of class 3 flammable liquid	122 hours /y

3.4 Pipes – incoming

The required information for the incoming pipeline is shown in Table 24.

Table 24 Description of the incoming pipeline

Pipe:	
Generalities	1 pipeline of 3 km length from a nearby refinery (pump utilities are situated in the refinery)
Total length in the facility	600 m
Diameter	12 inch
Flow rate	650 m^3/h
Pressure	15 bar
Installation	pipe bay
Diameter limit of the pool (facility limits, slope and sewer are considered to be installed at least at the boundaries of the facility)	75 m
Total time of transfer flammable liquids class 1	964 h/y
Total time of transfer flammable liquids class 2	758 h/y
Total time of transfer flammable liquids class 3	22 h/y

3.5 Surroundings of the depot

Figure 10 presents the map of the surroundings and Table 25 presents the corresponding population data. It is noted that persons working at the facility are not considered in the risk assessments of INERIS and RIVM. The risk to which employees are exposed, is evaluated in a different context. The ignition sources that were used by RIVM are shown in Figure 11.

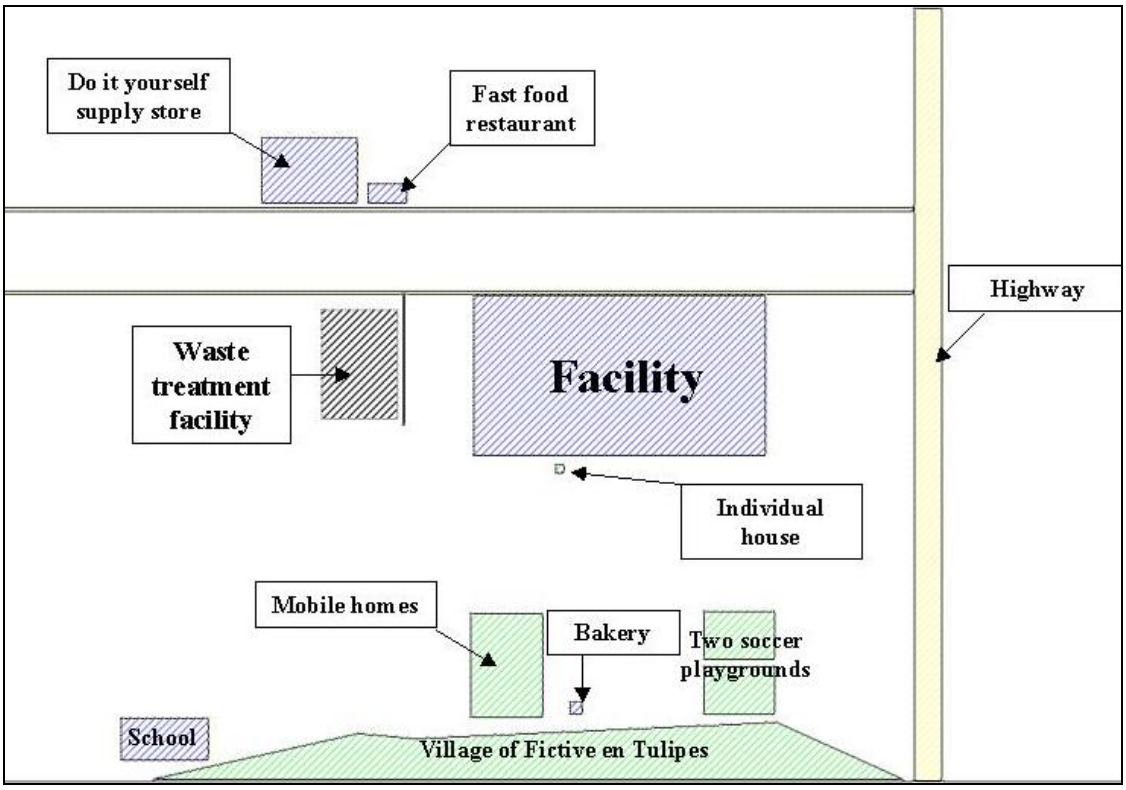

Figure 10 Surroundings of the depot

Table 25 Number of persons present in the vicinity of the depot

Object	Number of people (for INERIS)	Number of people during day (for RIVM)	Number of people during night (for RIVM)
Waste treatment facility	7	7	0
Fast food restaurant	15	15	0
Do It Yourself supply store	150	150	0
Soccer fields	44	44	0
Bakery	10	10	0
Mobile homes	25	15	30
School	150	150	30
Fictive en Tulipes	214	107	214
Individual house of Bob	1	1	1
Highway (4 ways with traffic jams)	1200/km	0	0

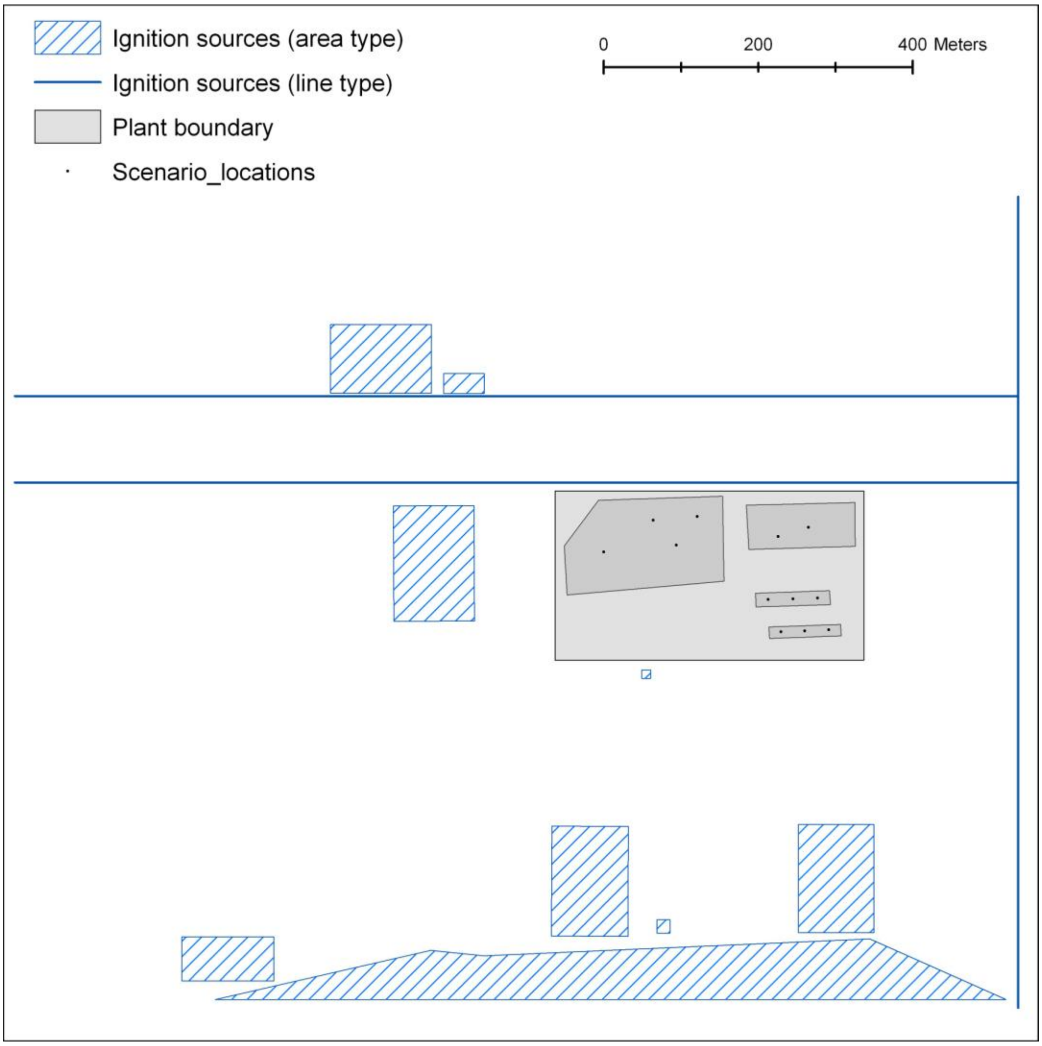

Figure 11 Ignition sources in the surrounding of the depot, as used by RIVM (ignition sources outside the facility are only relevant for societal risk, see section 2.4.2)

4 Central events: causes and consequences

Risk analysis involves the identification of mechanisms that lead to failure of equipment and loss of containment, and the identification of consequence effects that may follow the loss of containment. These paths from root causes via central events to consequence effects are usually visualised with a bow-tie (for example Figure 4). The current chapter explains which root causes are taken into account by INERIS and RIVM, how they are grouped into central events and which consequence effects are subsequently considered in the risk analysis. Section 4.1 focuses on the left side of the bow-tie, while section 4.2 describes the right side of the bow-tie.

4.1 Causes and central events

4.1.1 Methodology used by INERIS in this study

For the current case of a flammable liquid storage, the central events and most of the root causes are taken from a guideline published by the French national working group on flammable liquid depots GTDLI [9].

INERIS also used a set of root cause frequencies and level of confidence of barriers based on several safety reports. Therefore, these figures are presented here as an example. In some similar installations, the failure probability or the frequency of similar prevention barriers and root causes could be assessed as higher or lower.

A complete list of central events is given in Table 26. The corresponding diagrams are shown in Appendix 1.

Domino effects:
Some specific thresholds are defined by the ministry (see [3]) as a limit of intensity which could produce damages on infrastructure (200 mbar for overpressure effects and 8 kW/m^2 for thermal radiation effects). These damages are considered to lead to domino effects.
Each dangerous phenomenon which could lead to a domino effect is considered as a root cause for another dangerous phenomenon. The probability of occurrence of this root cause is equal to the probability of occurrence of the domino effect.
The analysis of domino effects used by INERIS in the framework of this study is presented in Appendix 2.

Table 26 Central events, causes and barriers (INERIS)

Installation	Central event	Frequency	Typical causes and prevention barriers
Tank	Pool in the bund	F2 (10^{-3} - 10^{-2}) per year per tank	See bow-tie diagrams n°1, 3, 5 and 7
	Pool on the top roof	F2 (10^{-3} - 10^{-2}) per year per tank	See bow-tie diagrams n°2 and 8
	Tank explosion	F4 (10^{-5} - 10^{-4}) per year per tank	See bow-tie diagrams n°4, 6 and 10
Loading area	Pool in loading area	F2 (10^{-3} - 10^{-2}) per year	See bow-tie diagrams n°11 and 12
	Tank truck explosion	F4 (10^{-4} - 10^{-3}) per year	
Pump area	Pool in the bund (pump rupture)	F3 (10^{-4} - 10^{-3}) per year	See bow-tie diagrams n°14
	Pool in the bund (pump leak)	F2 (10^{-3} - 10^{-2}) per year	See bow-tie diagrams n°13
Pipelines	Pool on site (pipe rupture)	F4 (10^{-5} - 10^{-4}) per year	See bow-tie diagrams n°16
	Pool on site (pipe leak)	F3 (10^{-4} - 10^{-3}) per year	See bow-tie diagrams n°15

4.1.2 *RIVM methodology*

An overview of the scenarios to be used according to the Dutch requirements for QRA calculations is given in Table 27. The data were derived from the generic frequencies that were presented in section 2.4.1 and the details for the depot that were presented in chapter 3. In particular, storage and (un)loading of domestic fuel oil (class 3 flammable liquid) is not considered in the QRA.
The column for typical root causes was omitted as very limited information was available on the typical root causes that lie behind the generic release scenarios (see section 2.4.1). When deriving failure scenarios and frequencies from historical data, it is difficult to take into account norms and standards for equipment, including barriers. Firstly, the presence or absence of appropriate standards and barriers is not always clearly reported in incident reports. Secondly, it is very difficult to determine to which extent standards and barriers were present in the reference data set. As a conservative approach it is assumed that the failure scenarios and frequencies that were derived from historic data, apply to equipment that is in accordance with the current standards of technique.

Table 27 Overview of central events (RIVM)

Installation	Central events (loss of containment scenarios)	Frequency
Tank	Catastrophic rupture	5×10^{-6} per year per tank
	Release of entire contents in 10 minutes	5×10^{-6} per year per tank
	Release from a hole with a diameter of 10 mm	1×10^{-4} per year per tank
Loading area	Rupture of the loading arm	1.6×10^{-4} per year for class 1 1.2×10^{-4} per year for class 2
	Leak from the loading arm	1.6×10^{-3} per year for class 1 1.2×10^{-3} per year for class 2
	Rupture of road tanker	1.1×10^{-5} per year for class 1 8.7×10^{-6} per year for class 2
	Leak from road tanker	5.5×10^{-7} per year for class 1 4.3×10^{-7} per year for class 2
	Domino	5.6×10^{-5} per year for class 1 4.4×10^{-5} per year for class 2
Pump area	Rupture of the pump	6.0×10^{-5} per year for class 1 4.7×10^{-5} per year for class 2
	Leak from the pump	2.6×10^{-3} per year for class 1 2.1×10^{-3} per year for class 2
Pipelines	Rupture of the pipe	6.6×10^{-6} per year for class 1 5.2×10^{-6} per year for class 2
	Leak from the pipe	3.3×10^{-5} per year for class 1 2.6×10^{-5} per year for class 2

4.1.3 Comparison of central events (INERIS and RIVM)

4.1.3.1 General

In the INERIS method, the working group identifies the central events to be used in the risk assessment, while the Dutch methodology uses predefined Loss of Containment scenarios. INERIS then aims to find an exhaustive list of causes for the central events defined, while in the Dutch approach simplicity is one of the key elements (i.e. in the Dutch approach, the use of a limited number of scenarios is accepted as long as this set is representative for all types of incidents that might occur).

The frequencies in the INERIS method depend on the frequencies of root causes and the probabilities of failure of the barriers. These frequencies and probabilities are determined by the working group and depend on the design, the construction and the environment of studied equipment. The frequencies in the Dutch approach are prescribed by the reference manual and apply to equipment that is in accordance with the current standards of technique (see section 2.4.1).

4.1.3.2 Tanks

Both INERIS and RIVM consider the possibility of a pool in the bund[7]. According to INERIS, this may either be a small pool or a large pool, which for simplicity are both modelled as a large pool. This event has a frequency between 10^{-3} and 10^{-2} per year per tank (F2, frequency of the small pool). According to RIVM, there is a probability of a small pool of 1×10^{-4} per year per tank, and a probability of a large pool of 1×10^{-5} per year per tank. The differences in frequencies can be explained as follows:

- For the small pool, the difference between INERIS and RIVM is between one and two orders of magnitude. This seems to be a difference of assessment.
- The specific likelihood of a large pool was not determined by INERIS because the small pool and the large pool were taken together (using the large pool for the calculation of effects). If more detail had been used in the INERIS analysis, the frequency of a pool that covers the whole bund would probably have been F3 or F4. The value from RIVM (1×10^{-5}) is at the lower side of this range.
- Considering the lack of data, it is difficult to identify the best values. This point would need further investigation.

INERIS further takes into account a pool on the tank roof (frequency range F2) and a tank explosion (frequency range F4). These events are not considered by RIVM because they are not expected to significantly contribute to the risk outside the establishment. RIVM on the other hand, further considers the ten minutes scenario (considered to be representative for overfilling or a major release from an orifice), with frequency 5×10^{-6} per year per tank which may be a spray with considerable vapour and aerosol formation (see Figure 6). In the methodology used here by INERIS, there is no central event that specifically describes the possibility of a spray release. However, this possibility would be considered along with the liquid leak scenario underlying the pool in the bund if the speed of liquid jet had been higher than 10 m/s.

4.1.3.3 Loading area

According to INERIS a pool in the loading area may occur due to failure of the loading arm, failure of a tank truck (leak or rupture) or overfill of the tank truck. For the current case it was not necessary to discriminate between large pools and small pools (the consequences are roughly similar), and the estimated frequency range is F2. RIVM also considers a pool in the loading area as a result of a leak or rupture of the loading arm and a leak or rupture of the tank truck, but does not consider the possibility of an overfill of the truck. The overall frequencies for the pool are in the same order of magnitude as those assessed by INERIS.
Apart from the pool in the loading area, INERIS considers the possibility of a tank truck explosion as a result of a domino effect (pool fire near tank truck) or ignition of vapours in the tank ([22]). The frequency range is F4 (10^{-5} to 10^{-4} per year). RIVM does not consider the possibility of an explosion of vapours in the tank, as it is not considered to be relevant for the risk outside the establishment. The

7 As was explained in section 2.4.1, the Dutch methodology considers specific release scenarios (e.g. leak from a 10 mm orifice) instead of the more general central events from INERIS (e.g. pool in bund). For reasons of simplicity, the instantaneous rupture of a tank and the rupture of pipes and pumps are supposed to give 'large pools', while leaks from vessels, pipes and pumps are supposed to give 'small pools'.

possibility of a domino effect is studied, but the expected consequence is a pool fire. The corresponding frequency for this depot is 1.0×10^{-4} per year (to be more specific: 5.6×10^{-5} for class 1 + 4.4×10^{-5} per year for class 2).

4.1.3.4 Pump area

With respect to the pump area, both INERIS and RIVM consider rupture and leak of the pump. The resulting consequence is a pool in the bund. The frequencies used by RIVM lie within the frequency range used by INERIS.

4.1.3.5 Pipelines

For the pipeline, again INERIS and RIVM both consider rupture and leak resulting in a pool on the site. The pool is not restricted by a bund. According to INERIS the frequency for a small pool is between 10^{-4} and 10^{-3} per year, whereas RIVM uses 5.9×10^{-5} per year (small leak in the pipeline). The frequency for a large pool is between 10^{-5} and 10^{-4} per year according to INERIS, which is in accordance with the frequency used by RIVM (1.2×10^{-5} per year for a full bore rupture of the pipeline).

4.2 Consequences of central events

4.2.1 INERIS methodology

4.2.1.1 Methodology

The bow-tie diagrams for loss of containment are defined by the working group. The fault tree part of the bow-tie was described in section 2.2.1.1. The current section describes the event tree.

It is underlined that in the development of the dangerous phenomenon, no distinction is made between direct and delayed ignition. When a flammable liquid is expected to ignite (see section 2.2.2), the resulting dangerous phenomenon may be a fire fed leak (that is: an ignited liquid jet) and/or a pool fire or a vapour cloud explosion (VCE) or a vapour cloud fire (VCF). These differences in the scenarios may be introduced by the distinction of direct ignition and delayed ignition. However, in order to take into account the uncertainties related to the distribution in the frequency of these events, the conservative hypothesis is used that all these events occur. This hypothesis means that all these dangerous phenomena have at this stage a conditional probability equal to 1.
For example, if the frequency of a gasoline release is assessed to be F2 and the ignition probability is 10^{-2}; then the probability of occurrence of the fire fed leak, the pool fire, the VCE and the VCF is F4.

Another point is that when protection barriers are identified in the event tree part of the bow-tie diagram, both failure and success of the barrier has to be considered. The effects of resulting dangerous phenomena have to be assessed if relevant.

All bow-tie diagrams used in this study are presented in Appendix 1.

4.2.1.2 Dangerous phenomena studied

Tanks

Table 28 Scenarios for floating roof tanks (INERIS)

Release event	Central event	Consequence effect	Used
Leak from vessel Leak from accessories Overfill	Grouped in the scenario 'pool in the bund'	Fire fed leak, pool fire, vapour cloud fire or vapour cloud explosion.	Yes
Pool on tank roof	Pool on tank roof	Tank top fire, maybe boil-over or thin-layer boil-over	Yes
Tank rupture	(not considered)	Vapour cloud fire or vapour cloud explosion, pool fire	No

Remarks

- *Boil-over and thin-layer boil-over:* boil-overs are considered when crude oils and heavy oils are stored. Thin-layer boil-overs are considered when diesel, domestic fuels, jet fuels and kerosene are stored.
- *Tank rupture:* the tank rupture is excluded from the analysis following the 'note de doctrine générale du 15 Octobre 2008 sur les Effets de vague dans les dépôts de liquides inflammables (y compris stockages au sein de sites industriels tels les raffineries)' (repealed by the 'circulaire du 10 Mai 2010', see [6]). This exclusion is applicable if specific tank design and maintenance norms are respected and inspections are realised following specific guidelines. The bund effectiveness in case of an event such as a tank rupture must also be assessed. In the framework of this study, we assume these conditions are respected.
- *Fire fed leak:* it is assumed that this dangerous phenomenon is not relevant for the present case.

Table 29 Scenarios for fixed roof tanks (INERIS)

Release event	Central event	Consequence effect	Used
Leak from vessel Leak from accessories Overfill	Gathered in a scenario 'pool in the bund'	Fire fed leak, pool fire, vapour cloud fire or vapour cloud explosion.	Yes
Tank rupture	(not considered)	Vapour cloud fire or vapour cloud explosion, pool fire	No
Flammable vapours in tank	Tank explosion	Tank explosion and tank fire, maybe boil-over or thin-layer boil-over	Yes
Fire impinging on tank	Tank pressurisation	Fireball after low pressurisation	Yes

Remarks

- *Boil-over and thin-layer boil-over:* boil-overs are considered when crude oils and heavy oils are stored. Thin-layer boil-overs are considered when diesel, domestic fuels, jet fuels and kerosene are stored.
- *Tank rupture:* The tank rupture is excluded from the analysis following the 'note de doctrine générale du 15 Octobre 2008 sur les Effets de vague dans les dépôts de liquides inflammables (y compris stockages au sein de sites industriels tels les raffineries)' (repealed by the 'Circulaire du 10 May 2010', see [6]). This exclusion is applicable if specific tank design and maintenance norms are respected and inspection are realised following specific guidelines. The bund effectiveness in case of an event such as a tank rupture must also be assessed. In the framework of this study, we assume these conditions are respected.
- *Fire fed leak:* it is assumed that this dangerous phenomenon is not relevant for the present case.

Loading area

Table 30 Scenarios for loading arms (INERIS)

Central event	Consequence effect	Used
Rupture – pool in the loading area	Fire fed leak, pool fire, VC fire, VC explosion.	Yes

Remarks

- *Fire fed leak:* it is assumed that this dangerous phenomenon is not relevant for the present case.
- *Rupture and leak of the loading arm:* the frequency of the rupture is generally lower than the frequency of the leak of a loading arm. However, the release rate is larger and therefore the consequences of a rupture will be bigger. In this study, no distinction was made between leak and rupture of the loading arm. In a conservative approach, the consequence area of the rupture was used both for rupture and for leak of the loading arm.

Table 31 Scenarios for tank trucks (INERIS)

Release event	Central event	Consequence effect	Used
Flammable vapours in tank	Tank explosion	Explosion	Yes
Leak	Gathered in a scenario 'pool in the loading area'	Fire fed leak, pool fire, vapour cloud fire, vapour cloud explosion.	Yes
Overfill			

Remarks
- *Fire fed leak:* it is assumed that this dangerous phenomenon is not relevant for the present case.

Pumps

Table 32 Scenarios for pumps (INERIS)

Release event	Central event	Consequence effect	Used
Rupture	Gathered in a scenario 'pool in the pump area'	Fire fed leak, pool fire, vapour cloud fire, vapour cloud explosion.	Yes
Leak			

Remarks
- *Fire fed leak:* it is assumed that this dangerous phenomenon is not relevant for the present case.
- *Rupture and leak of pumps:* the frequency of the rupture is generally lower than the frequency of the leak of the pump. However, the release rate is larger and therefore the consequences of a rupture will be bigger. In this study, no distinction was made between leak and rupture of the pump. In a conservative approach, the consequence area of the rupture was used both for rupture and for leak of the pump.

Pipeline

Table 33 Scenarios for pipelines (INERIS)

Release event	Central event	Consequence effect	Used
Leak	Gathered in a scenario 'pool in the facility'	Fire fed leak, pool fire, vapour cloud fire, vapour cloud explosion	Yes
Rupture			

Remarks
- *Fire fed leak:* it is assumed that this dangerous phenomenon is not relevant for the present case.
- *Pool in the facility:* it is assumed that the pool will not spread out of the boundaries of the facility. It is further assumed that the pool radius in case of a rupture of the pipeline is limited to a maximum of 75 m (pool surface area 17,700 m^2).
- *Rupture and leak of pipes:* the frequency of the rupture is generally lower than the frequency of the leak of the pipeline. However, the release rate is larger and therefore the consequences of a rupture will be bigger. In this study, no

distinction was made between leak and rupture of the pipeline. In a conservative approach, the consequence area of the rupture was used both for rupture and for leak of the pipeline.

4.2.1.3 Models used

The consequence models used by INERIS are presented in Table 34.

Table 34 Models used by INERIS

Dangerous phenomenon	Consequence model	Model developer	Theory used	Prescribed by legislation?
Pool fire	FNAP ([23])	INERIS	Emitting Solid Flame	yes, circular of 10 May 2010 ([6])
Pool evaporation[8]	PHAST	DNV	TNO and Mackay and Matsugu correlation	yes, circular of 10 May 2010 ([6])
Boil-over	Model of boil-over ([24])	INERIS	Emitting Static Fireball at a fixed height	no
Thin-layer boil-over	Model of Thin-layer boil-over ([24])	INERIS	Emitting fire cylinder from the ground to a fixed height	yes, circular of 10 May 2010 ([6])
Tank pressurisation	Model of pressurisation	UFIP	/	yes, circular of 10 May 2010 ([6])
Tank explosion	Projex	INERIS	Explosion Energy from Brode formula + Multi Energy abacus	no
Road tank explosion	Projex	INERIS	Explosion Energy from Brode formula + Multi Energy abacus	no
Tank explosion	Model of tank explosion ([25])	Flammable liquids work group	Close to the Projex one	yes, circular of 10 May 2010 ([6])
UVCE	Multi Energy	TNO	Strength assessment of explosion through a severity class choice	yes, circular of 10 May 2010 ([6])
VCE	Effex	INERIS	Quantification of pressure increasing in the building + Explosion Energy quantification + Multi Energy abacus	no
VCE	Projex	INERIS	Explosion Energy from Brode formula + Multi Energy abacus	no
Jet fire	PHAST	DNV	Different empirical correlations	no
Jet explosion	Exoris	INERIS	Quantification of flames speed in the jet	no

8 Calculations carried out for D5 and F3 weathers.

4.2.1.4 Consequence distances

The dangerous phenomenon that gives the largest consequence distance is the boil-over of the crude oil tank (tank n°1): 630 m for the significant lethal effect threshold and 1 km for the irreversible effect threshold[9]. Fireballs resulting from pressurisation of fixed roof tanks also give significant consequence distances: 100 m for the significant lethal effect threshold.
However, these dangerous phenomena are usually considered as low kinetic phenomena. In order to classify a dangerous phenomenon as low kinetic, an assessment of the duration between the beginning of the accident and the moment where dangerous effects affect the population is made (for example in the case of the tank 1 boil-over, the assessed time is more than 52 hours). With regard to this assessment, local authorities (taking into account the advice of emergency services) may classify a dangerous phenomenon as low kinetic if it is thought that the population can be evacuated in time. Low kinetic dangerous phenomena are not taken into account in the PPRT 'aléa' zoning process. But still, areas which could be impacted by low kinetic phenomena may have limitations on the land-use (mainly related to evacuation time). For example, these limitations may be applied for large public buildings where the evacuation is difficult.
In the framework of this study, we assume that boil-over, thin-layer boil-over and tank pressurisations are low kinetic dangerous phenomena[10].

Fast kinetic scenarios are therefore more important for land-use planning issues. In the present case, in the north of the facility, pool fires in tank bunds and tank explosions are the dangerous phenomena that dominate the risk. In these areas, the effects of vapour cloud explosions do not reach the thresholds defined by the regulation. The reason is that there are no obstructed areas within the flammable cloud envelope.
In the south-east of the facility, the vapour cloud explosions resulting from a leak in the pump and loading areas are the most important dangerous phenomena with regard to the risk. Indeed, these areas are considered as congested areas. Vapour cloud explosions which may occur in these congested area, are considered to be potentially violent. The pool fire in the loading area is of less importance.
In the south-west and the south of the facility, the risk is dominated by dangerous phenomena resulting from pipe leaks; namely, the pool fire, the vapour cloud fire and the vapour cloud explosion. These dangerous phenomena give large effect distances although the sizes of the pool resulting from the leak of the pipeline have been restricted to a radius of 75 m (it is assumed that the pool size is restricted by the layout of the facility). The radius of 75 m is believed to be sufficiently conservative. The pool fire and the flash fire define the risk in nearest areas, because of their high probability of occurrence and the large effect distances. The vapour cloud explosion defines the risk in further areas.

9 See Table 1 for end-values for significant lethal effect and irreversible effects.
10 This assumption chosen by INERIS at the beginning of the study may be questionable for thin layer boil-over: this dangerous phenomenon may be considered as a 'fast kinetic phenomenon'. Calculations have been performed in order to know what would be the impact on the results of the study if this assumption is changed. It appears that the 'aléa' maps would not be significantly modified because of the 'tank explosion' scenarios. Indeed, these scenarios have been identified for the same vessels as those concerned by thin layer boil-over and have both higher probabilities and wider consequences.

Actually, this last dangerous phenomenon (vapour cloud explosion after the rupture of the pipeline) dominates the risk in all distant areas with effect distances of 75 m for significant lethal effect threshold and 460 m for indirect effects. The reason of the violence of this explosion is the presence of an obstructed area in the centre of the facility (where tank wagons are stationed) together with a very large volume of vapours resulting from the pipe rupture.

Table 35 presents the general results of the quantification of probability and consequences of dangerous phenomena.

Notes concerning Table 35:

- The following effect distances in Table 35 represent *distances from the boundary of the bund*: pool fires, vapour cloud fires (VCF) and vapour cloud explosions (VCE) except the vapour cloud explosion following a pipe rupture (in which case the distance is from the centre of the congested area).
- The following effect distances in Table 35 represent *distances from the centre of a tank*: tank top fires, tank explosions, boil-overs and fireballs.
- The distance for the VCE following pipe rupture is taken *from the centre of the congested area*.
- For pool fires two effect distances are reported for each effect level. The reason is that the pool fire is not circular due to the rectangular shape of the bunds. The first distance represents the effect distance from the larger side of the bund, the second the effect distance from the smaller side.
- The last column in Table 35 gives distances to Dutch limit values. These values are presented for a comparison of the consequence models (see section 4.2.3). Only a limited number of scenarios have been analysed.

Table 35 Results of the quantification of the probabilities and the consequences of dangerous phenomena (INERIS)

Nr	Name	Prob. class	Type of effects	Kinetic	Significant lethal effects (m)	Lethal effects (m)	Irreversible effects (m)	Indirect effects (m)	NL lower limit (9.8 kW/m^2 or 100 mbar)
1	Pool fire Bund A tank 1 leak	D	Thermal	Fast	45; 55	75; 95	110; 140	Not applicable	30; 40
2	Pool fire Bund A tank 2 leak	D	Thermal	Fast	45; 55	75; 95	110; 140	Not applicable	30; 40
3	Pool fire Bund A tank 3 leak	D	Thermal	Fast	45; 55	75; 95	110; 140	Not applicable	30; 40
4	Pool fire Bund A tank 4 leak	D	Thermal	Fast	45; 55	75; 95	110; 140	Not applicable	30; 40
5	Pool fire Bund B tank 5 leak	D	Thermal	Fast	30; 45	50; 70	70; 100	Not applicable	25; 35
6	Pool fire Bund B tank 6 leak	D	Thermal	Fast	30; 45	50; 70	70; 100	Not applicable	25; 35
7	Pool fire Bund B tank 7 leak	E	Thermal	Fast	30; 45	50; 70	70; 100	Not applicable	25; 35
8	VCF bund A tank leak	D	Thermal	Fast	40	40	44	Not applicable	Not calculated
9	VCE bund A tank leak	D	Overpressure	Fast	0	0	65	115	40
10	VCF bund B tank leak	D	Thermal	Fast	40	40	44	Not applicable	Not calculated
11	VCE bund B tank leak	D	Overpressure	Fast	0	0	95	170	50
..	Tank top fire tank 1	D	Thermal	Fast	0	0	0	Not applicable	0
..	Tank top fire tank 2	E	Thermal	Fast	0	0	0	Not applicable	0
..	Tank top fire tank 3	E	Thermal	Fast	0	0	0	Not applicable	0
..	Tank top fire tank 4	E	Thermal	Fast	0	0	0	Not applicable	0
..	Tank top fire tank 5	D	Thermal	Fast	0	0	0	Not applicable	0
..	Tank top fire tank 6	E	Thermal	Fast	0	0	0	Not applicable	0
12	Tank top fire tank 7	E	Thermal	Fast	0	0	20	Not applicable	0
13	Tank explosion tank 2	D	Overpressure	Fast	45	60	130	260	Not calculated
14	Tank explosion tank 3	D	Overpressure	Fast	45	60	130	260	Not calculated
15	Tank explosion tank 4	D	Overpressure	Fast	45	60	130	260	Not calculated
16	Tank explosion tank 6	D	Overpressure	Fast	30	35	80	160	Not calculated
17	Tank explosion tank 7	D	Overpressure	Fast	30	35	80	160	Not calculated
18	Boil-over tank 1	E	Thermal	Slow	630	820	1000	Not applicable	480

	Name	Prob. class	Type of effects	Kinetic	Significant lethal effects (m)	Lethal effects (m)	Irreversible effects (m)	Indirect effects (m)	NL lower limit (9.8 kW/m^2 or 100 mbar)
19	Thin-layer boil-over tank 2	E	Thermal	Slow	40	55	65	Not applicable	Not calculated
20	Thin-layer boil-over tank 3	E	Thermal	Slow	40	55	65	Not applicable	Not calculated
21	Thin-layer boil-over tank 4	E	Thermal	Slow	40	55	65	Not applicable	Not calculated
22	Thin-layer boil-over tank 7	E	Thermal	Slow	20	25	30	Not applicable	Not calculated
23	Fireball tank 2	E	Thermal	Slow	100	130	165	Not applicable	Not calculated
24	Fireball tank 3	E	Thermal	Slow	100	130	165	Not applicable	Not calculated
25	Fireball tank 4	E	Thermal	Slow	100	130	165	Not applicable	Not calculated
26	Fireball tank 6	E	Thermal	Slow	30	40	50	Not applicable	Not calculated
27	Fireball tank 7	E	Thermal	Slow	40	50	65	Not applicable	Not calculated
28	Pool fire loading area	D	Thermal	Fast	20; 30	25; 40	30; 55	Not applicable	20; 30
29	VCF loading area	D	Thermal	Fast	15	15	17	Not applicable	Not calculated
30	VCE loading area	D	Overpressure	Fast	40	55	125	250	70
31	Tank explosion loading area	D	Overpressure	Fast	20	25	50	100	30
32	Pool fire pump area	D	Thermal	Fast	25; 35	30; 45	35; 60	Not applicable	Not calculated
33	VCF pump area	D	Thermal	Fast	20	20	22	Not applicable	Not calculated
34	VCE pump area	D	Overpressure	Fast	45	60	150	300	80
35	Pool fire pipe rupture	C	Thermal	Fast	105	140	175	Not applicable	95
36	VCF pipe rupture	C	Thermal	Fast	125	125	130	Not applicable	Not calculated
37	VCE pipe rupture	C	Overpressure	Fast	75	100	230	460	125
38	Pool fire loading area (limited release duration)	C	Thermal	Fast	16	19	23	Not applicable	15
..	VCF loading area (limited release duration)	C	Thermal	Fast	0	0	0	Not applicable	0
..	VCE loading area (limited release duration)	C	Overpressure	Fast	0	0	0	0	0

4.2.2 *RIVM methodology*

4.2.2.1 Methodology

As explained in section 2.4, Dutch risk analyses for establishments are carried out using SAFETI-NL.

The starting point for consequence calculations in SAFETI-NL is the definition of release scenarios, such as rupture of a tank, leak from a tank, rupture of pipe, et cetera. The software subsequently calculates the amount of vapour produced and the dispersion of the vapour cloud. Three phenomena contribute to the vapour cloud: (i) flash evaporation as a result of initial depressurisation, (ii) evaporation from the surface of droplets prior to rainout and (iii) evaporation from the liquid pool after rainout (see also Figure 6). The software also calculates the size of the pool, which is relevant for the pool fire and pool evaporation.

The software then automatically determines which effects need to be considered (see section 2.4.2). For an instantaneous release of flammable liquids, this will generally be a flash fire, a pool fire and an explosion. For a continuous release of flammable liquids, a jet fire, a pool fire, a vapour cloud fire and a vapour cloud explosion are considered. The possibility of an explosion is taken into account if and only if the flammable mass in the cloud at the time of ignition exceeds a threshold specified in the software.

The assumptions used for consequence and risk modelling for atmospheric storage tanks have recently been studied in detail by RIVM ([19]). The analysis resulted in further specifications for QRA modelling, which were communicated to stakeholders in January 2009[11]. Obviously, these specifications have also been used in the current study.

Regarding discharge and dispersion, the following assumptions (which are all in accordance with the Reference Manual and additional specifications on the SAFETI-NL website) are most relevant:

- The instantaneous release of the contents of a storage tank is assumed to produce an evaporating liquid pool without (significant) vapour formation prior to rainout. The release of the entire contents in 10 minutes on the other hand, may give substantial vapour formation prior to rainout, which is expected to be representative for overfill scenarios.
- The consequences of releases of class 1 hydrocarbon mixtures are calculated using n-hexane as a representative material. The consequences of releases of class 2 hydrocarbon mixtures are calculated using n-nonane. The reason of these choices is that RIVM has more confidence in applying the SAFETI-NL models to pure substances than to mixtures.

11 See 'veelgestelde vragen' (frequently asked questions) on the SAFETI-NL webpage: http://www.rivm.nl/milieuportaal/bibliotheek/modellen/safeti-nl/SAFETI-NL-beveiligde-pagina.jsp.

- For releases from storage tanks, the maximum pool size is related to the size of the bund. For instantaneous releases the maximum pool size is set to 150% of the bund surface area and for continuous releases 100%. For releases in the pump and storage areas, the maximum pool size is related to the size of the water recovery areas. Again 150% is used for instantaneous releases and 100% for continuous releases. For releases from the aboveground pipeline, it is assumed that the maximum pool radius is 75 m. This upper bound is assumed to be sufficiently conservative for the considered establishment.
- For rupture of the pump, rupture of the loading arm and rupture of the pipeline, both flow from the upstream end and flow from the downstream end of the pipe are considered. The flow from the upstream end is assumed to be 150% of the normal pumped flow. The flow from the downstream end depends on the liquid head of the connected tanks/tank cars and the distance to these tanks/tank cars. This back flow is calculated using SAFETI-NL.

4.2.2.2 Dangerous phenomena and models used

As discussed in the previous section, SAFETI-NL automatically determines which effects need to be considered. This depends on the type of release (instantaneous or continuous) and the amount of vapour and liquid present at the time of ignition. For flammable liquids, the most important phenomena are flash fire, pool fire and (in some cases) vapour cloud explosion.

The dispersion of the vapour cloud is calculated using the Unified Dispersion Model in SAFETI-NL. The fire effects are calculated with various different models in SAFETI-NL. All these models are extensively described in the SAFETI-NL documentation. These models are usually constructed from various empirical correlations and sub-models published in the literature. A summary is given in Table 36.

Table 36 Consequence models used by RIVM

Dangerous phenomenon	Effect model used by RIVM	Model developer	Theory used
Pool fire	SAFETI-NL	DNV	Emitting solid flame model
Jet fire	SAFETI-NL	DNV	Emitting solid flame model; empirical correlations for gaseous jets modified for 2-phase jets.
Vapour cloud fire (flash fire)	SAFETI-NL	DNV	Integral model for dispersion
Vapour cloud explosion	SAFETI-NL	DNV	TNT equivalence model

Remarks

- The possibility of a vapour cloud explosion is considered if and only if the combustion energy of the flammable mass in the cloud exceeds 5 GJ, regardless of the presence (or absence) of confined or congested areas. When this energy is exceeded, the consequences of the vapour cloud explosion are calculated with a simple TNT equivalence model, assuming that 10% of the flammable mass in the cloud detonates like TNT[(12)].

4.2.2.3 Consequence distances

The consequence distances calculated with SAFETI-NL are shown in Table 37. The distances for the flash fire and jet fire are usually small, with the exception of 10 minute release scenarios for flammable liquids of class 1 (tank 1, tank 5 and tank 6). The pool fires generate a heat radiation of 9.8 kW/m^2 (1% lethality) at a distance of 30 m from the edge of the pool.

Releases in the pump and loading area will hardly affect persons outside the establishment (1% lethality is calculated at 10 m outside the border). The size of the flammable cloud is limited for these scenarios and, as a result, explosions are not considered for the pump and loading area. Rupture of the pipeline on the other hand, may give an explosion. Under stable weather conditions, an overpressure of 100 mbar may occur at a distance of 250 m from the pipe.

The largest consequence distances are found for the crude oil and gasoline storage tanks (tank 1 and tank 5 respectively), and more particularly for the 10 minute release scenarios for these tanks. According to the calculations, the distance to 100 mbar is 500 to 600 m under stable weather conditions. As discussed in [19], the 10 minute release scenario is regarded as representative for overfill incidents which have sometimes produced significant explosion damage.

When looking at Table 37, it is expected that the overall risk will be high within 130 m distance from the modelled release locations and will rapidly decrease beyond this distance (as few scenarios have a consequence distance higher than 130 m). This will be verified in section 5.2.1.

12 A more advanced model to calculate overpressures from vapour cloud explosion is the TNO Multi Energy model. Different curves can be used for different types of vapour cloud explosions. Curve 10 is used for a detonating vapour cloud. Another input parameter of the Multi Energy is the fraction of the flammable mass in obstructed regions.
It was observed in the Purple Book (**Fout! Verwijzingsbron niet gevonden.**) that if curve 10 of the Multi Energy model is used with a fraction of flammable mass in an obstructed region of 0.08, the same explosion distances are obtained as with the simple TNT equivalence method currently used in SAFETI-NL.

Table 37 Consequence distances for RIVM scenarios (in meters)

	Flash fire (LFL)	**Jet fire (9.8 kW/m²)**	**Pool fire (9.8 kW/m²)**	**VCE (100 mbar)**
Scenario	D5 / F1.5 [13]	D5 / F1.5 [13]	D5 / F1.5 [13]	D5 / F1.5 [13]
Bund A				
Tank 1-cat. rupture	90 / 180	x / x	130 / 120	x / 240
Tank 1-release in 10 min.	230 / 470	290 / 320	130 / 120	310 / 630
Tank 1-release from 10 mm	5 / 5	15 / 15	30 / 25	x / x
Tank 2-cat. rupture	30 / 30	x / x	130 / 120	x / x
Tank 2-release in 10 min.	25 / 20	60 / 65	130 / 120	x / x
Tank 2-release from 10 mm	5 / 5	5 / 5	35 / 25	x / x
Tank 3-cat. rupture	30 / 25	x / x	130 / 120	x / x
Tank 3-release in 10 min.	25 / 20	60 / 65	130 / 120	x / x
Tank 3-release from 10 mm	5 / 5	5 / 5	35 / 25	x / x
Tank 4-cat. rupture	30 / 25	x / x	130 / 120	x / x
Tank 4-release in 10 min.	25 / 20	60 / 65	130 / 120	x / x
Tank 4-release from 10 mm	5 / 5	5 / 5	35 / 25	x / x
Bund B				
Tank 5-cat. rupture	30 / 30	x / x	80 / 70	x / x
Tank 5-release in 10 min.	200 / 340	250 / 260	90 / 75	250 / 460
Tank 5-release from 10 mm	5 / 5	15 / 15	35 / 25	x / x
Tank 6-cat. rupture	90 / 10	x / x	80 / 70	80 / x
Tank 6-release in 10 min.	90 / 140	120 / 120	80 / 70	120 / 240
Tank 6-release from 10 mm	5 / 5	15 / 15	30 / 25	x / x
Pump area				
Pump-rupture (class 1)	35 / 25	60 / 55	45 / 35	x / x
Pump-leak (class 1)	10 / 10	20 / 20	35 / 30	x / x
Pump-rupture (class 2)	5 / 5	15 / 15	40 / 35	x / x
Pump-leak (class 2)	5 / 5	15 / 5	35 / 30	x / x
Loading area				
Loading arm-rupture (class 1)	5 / 5	45 / 40	40 / 30	x / x
Loading arm-leak (class 1)	10 / 10	25 / 25	35 / 30	x / x
Tank car-rupture (class 1)	40 / 5	x / x	40 / 35	x / x
Tank car-leak (class 1)	5 / 5	40 / 35	40 / 30	x / x
Tank car-domino fire (class 1)	x / x	x / x	40 / 35	x / x

13 The effect distances are calculated for B3, D1.5, D5, D9, F1,5 weather conditions. The results presented here are shown as representative examples. All effect distances are given from the centre of the tank or any other equipment.

	Flash fire (LFL)	Jet fire (9.8 kW/m²)	Pool fire (9.8 kW/m²)	VCE (100 mbar)
Scenario	D5 / F1.5 (14)	D5 / F1.5 (13)	D5 / F1.5 (13)	D5 / F1.5 (13)
Loading arm-rupture (class 2)	5 / 5	10 / 10	40 / 30	x / x
Loading arm-leak (class 2)	5 / 5	10 / 10	40 / 30	x / x
Tank car-rupture (class 2)	5 / 5	x / x	40 / 35	x / x
Tank car-leak (class 2)	5 / 5	10 / 10	40 / 30	x / x
Tank car-domino fire (class 2)	x / x	x / x	40 / 35	x / x
Pipeline				
Pipeline-rupture (class 1)	40 / 40	70 / 70	100 / 90	x / 250
Pipeline-leak (class 1)	90 / 140	80 / 95	75 / 70	100 / 180
Pipeline-rupture (class 2)	5 / 5	15 / 15	100 / 90	x / x
Pipeline-leak (class 2)	40 / 30	45 / 40	120 / 100	x / x

4.2.3 *Comparison of consequences*

In the current section, consequence outcomes of INERIS and RIVM are compared. The differences are illustrated with figures showing the areas that may be exposed to fire or explosion effects. For the fire footprint, the LFL was chosen if the event is a flash fire. A heat radiation level of 9.8 kW/m^2 was chosen if the event is a prolonging fire, for example a pool fire. This radiation level of 9.8 kW/m^2 corresponds to the lowest effect level used in the Dutch method (1% probability of lethality[15]). For the explosion footprint, the overpressure level of 100 mbar was chosen. According to the Dutch methodology, this overpressure level will give significant damage to buildings, with an estimated 2.5% probability of lethality for people residing indoors. This 100 mbar is also the lowest effect level that is used in the Dutch QRA methodology.

4.2.3.1 Storage tanks (bund A and bund B)

Bund A contains one floating roof crude oil tank and three fixed roof jet fuel tanks. Figure 12 shows which areas will be affected by a fire if an incident occurs with one of the storage tanks (INERIS methodology in yellow and RIVM methodology in purple).
INERIS considers a fire in the bund (tanks 1, 2, 3 and 4), a boil-over (tank 1) and a fireball after tank roof failure from heat impingement (tanks 2, 3 and 4). The fire in the bund may occur rapidly after the start of the incident ('fast kinetic events'). The corresponding distance to 9.8 kW/m^2 is 40 m along the long side of the bund, and 30 m along the short side of the bund. Fireball and boil-over may occur several (or many) hours after the start of the incident ('slow kinetic events'). The corresponding distance to 9.8 kW/m^2 is 100 m and 480 m respectively.

14 The effect distances are calculated for B3, D1.5, D5, D9, F1,5 weather conditions. The results presented here are shown as representative examples. All effect distances are given from the centre of the tank or any other equipment.
15 An exposure time of 20 s is assumed, see section 2.4.3.

For RIVM, the dominant fire outcomes for bund A are a pool fire and a flash fire. The pool fire has a radius of 130 m from the centre of the tank which gives a bigger hazard zone than the INERIS pool fire. This is partly explained by the fact that RIVM takes into account bund overtopping (pool size equal to 150% of bund size). The flash fire following the '10 minute release' has an ellipsoid shape and – for weather class D5 – may reach a maximum distance of 230 m from the tank location. In the current interpretation of RIVM this scenario is representative for (very) large continuous releases, for example overfilling or a release from the largest connection to the tank with possible increase of hole size (see section 2.4.1).
The Dutch methodology does not take into account the possibility of a boil-over, nor the possibility of a fireball following tank roof failure after heat impingement. Dutch QRA calculations focus on lethality, and for the 'slow kinetic events' it is assumed that emergency services will have sufficient time to evacuate the population. For overfill incidents, INERIS does not expect that the vapour cloud will go far outside the bund. Instead, an overfill incident is assumed to give a pool in the bund and possibly a corresponding flash and pool fire.

Figure 13 shows which areas may be affected by an explosion if an incident occurs with one of the tanks in bund A (INERIS methodology in yellow and RIVM methodology in purple). For fixed roof tanks, INERIS considers the possibility of a tank explosion (ignition of a flammable mixture inside the tank). The expected distance to 100 mbar is about 45 m. In the Dutch method, tank explosions are not taken into consideration for atmospheric liquids (such a tank explosion is expected to produce limited hazard outside the establishment). The Dutch method does consider the possibility of a vapour cloud explosion following a large scale continuous release (10 minutes scenario). The distance to 100 mbar is 310 m if the weather is D5 and 630 m if the weather is F1.5 (see Table 37). As noted in the previous paragraph, this scenario is supposed to represent (among others) overfill scenarios, and in particular explosions similar to Buncefield (Hemel Hempstead) on 11 December 2005. INERIS on the other hand, derives a smaller cloud size for overfill scenarios, which does not reach a congested or partly confined area.

The same discussion largely applies to bund B. Several incident scenarios will give a pool in the bund, with possible flash and pool fire. INERIS further considers a tank explosion for tank 6 and a fireball after pressurisation of tank 6. For tank 7 (a fixed roof tank filled with domestic fuel oil), INERIS also considers a thin-layer boil-over as a slow kinetic event. RIVM does not consider the possibility of a tank explosion, nor the slow kinetic events. On the other hand, RIVM does obtain a vapour cloud outside the bund (related to the 10 minutes scenario for tank 5) that may ignite and give a significant flash fire or vapour cloud explosion.

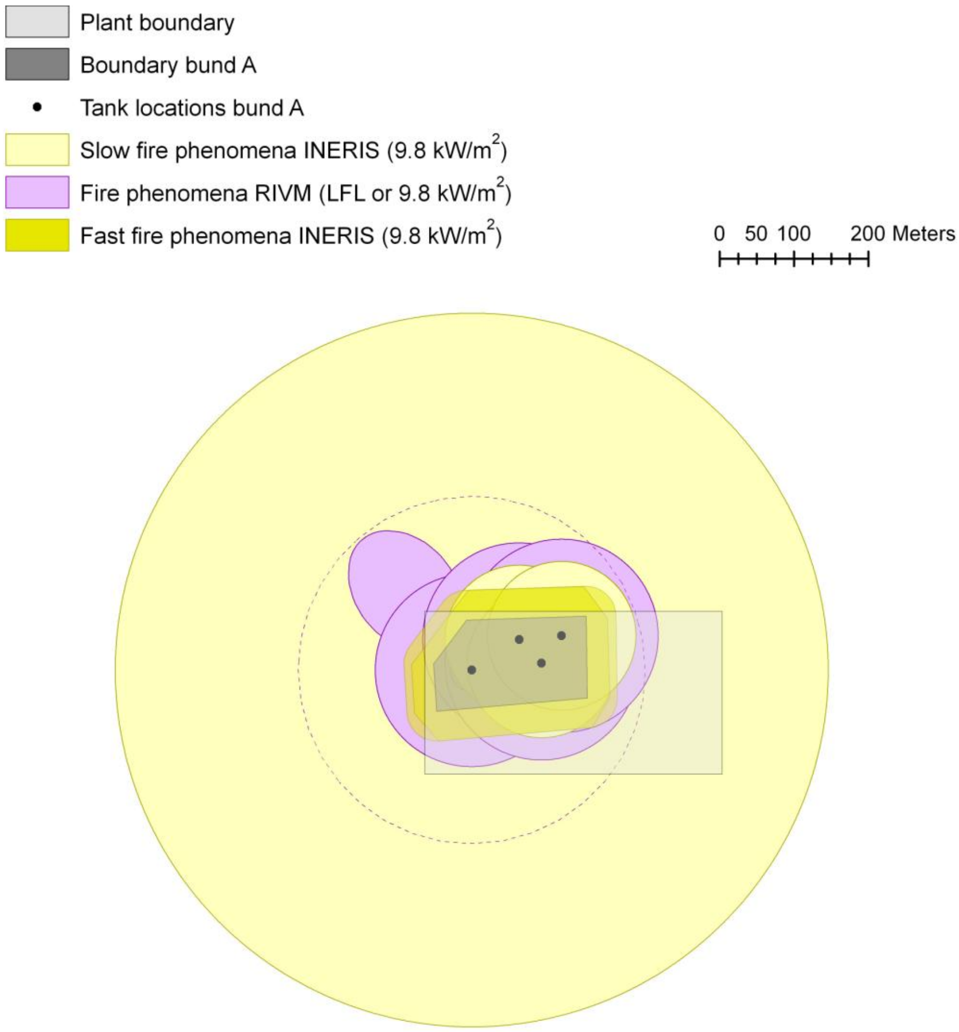

Figure 12 Fire phenomena for storage tanks in bund A (weather type D5)

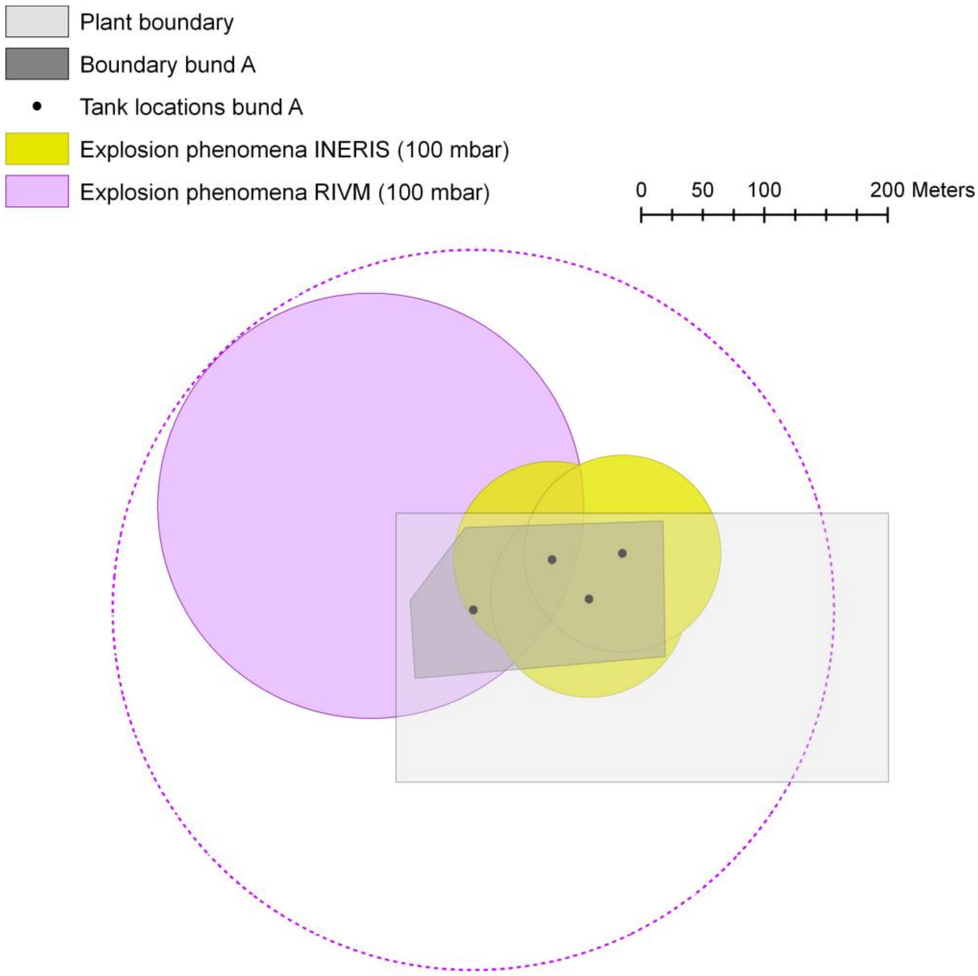

Figure 13 Explosion phenomena for storage tanks in bund A (weather type D5)

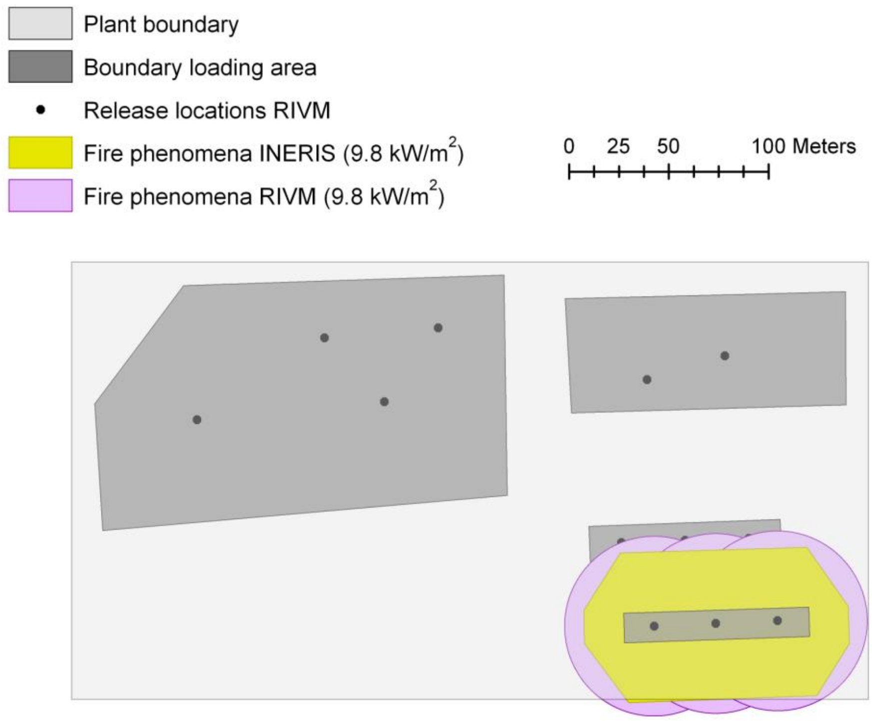

Figure 14 Fire phenomena for the loading area (weather type D5)

4.2.3.2 Pump area and loading area

The scenarios for the pump area and the loading area are largely similar between INERIS and RIVM (see section 4.1.3).
Figure 14 shows which areas will be affected by a fire if an incident occurs in the loading area (INERIS methodology in yellow and RIVM methodology in purple). Both INERIS and RIVM consider a pool fire as a result of a rupture of the loading arm or a rupture of the tank car. The calculated heat radiation distances are in the same order of magnitude, but INERIS uses a more realistic shape for the pool fire.
INERIS further considers the possibility of a vapour cloud explosion as a result of congestion in the loading area (see Figure 15). According to SAFETI-NL on the other hand, the amount of mass in the vapour cloud is limited and does not exceed the Dutch threshold for a vapour cloud explosion. As a result, an explosion in the loading area is not considered in the Dutch methodology.

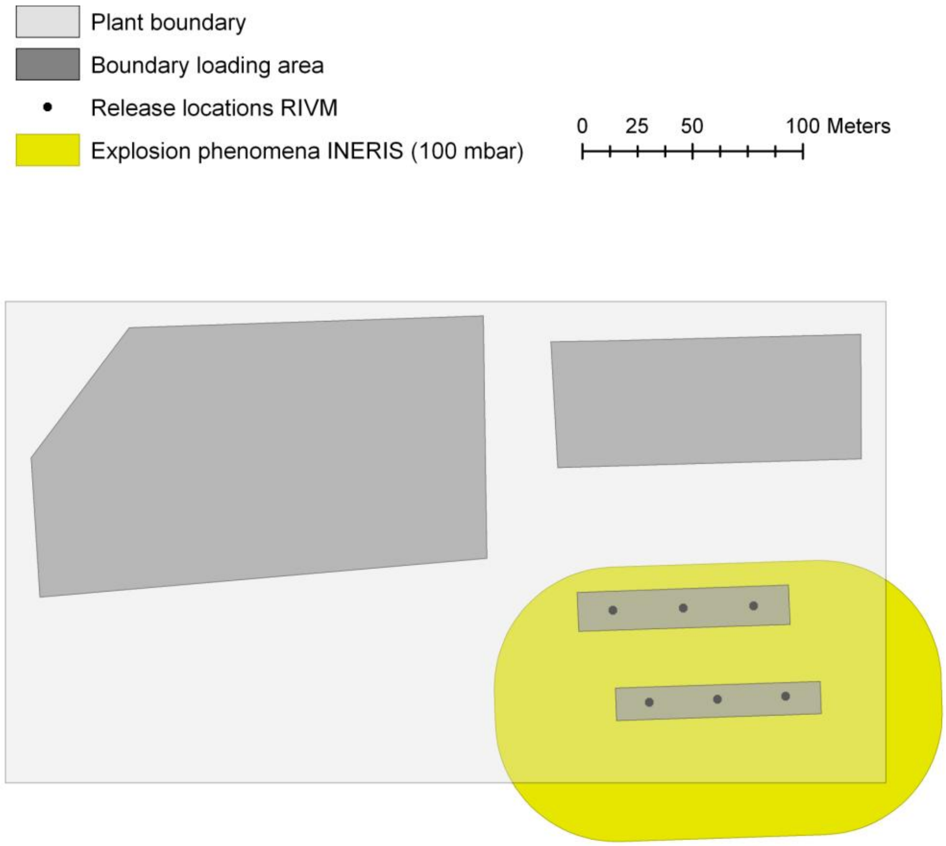

Figure 15 Explosion phenomena for the loading area (weather type D5)

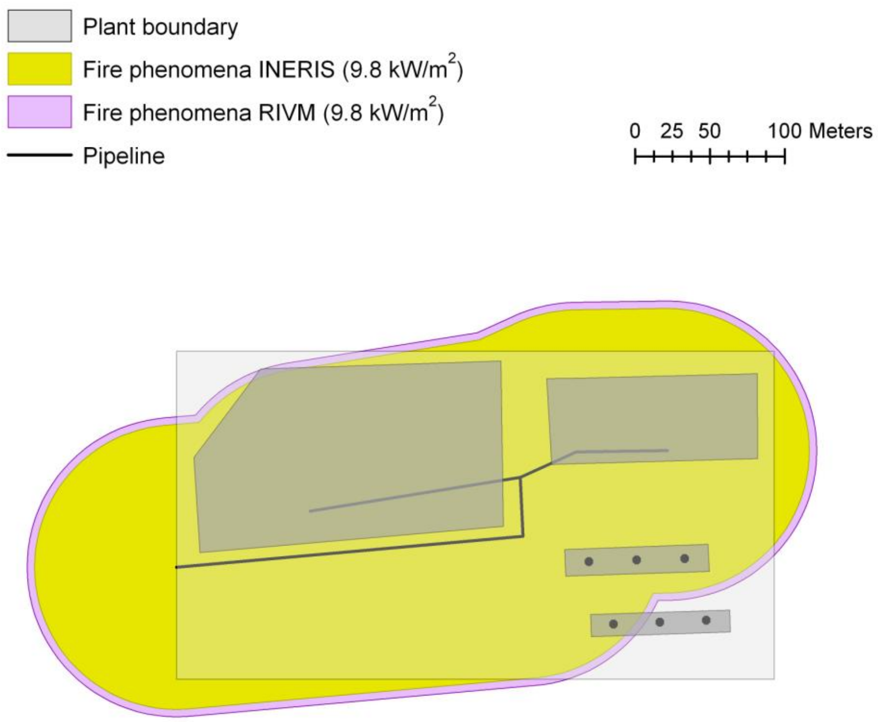

Figure 16 Fire phenomena for the pipeline (weather type D5)

4.2.3.3 Pipeline

The areas that are vulnerable for fire and explosion effects in case of an incident with the (aboveground) pipeline at the establishment are shown in Figure 16 and Figure 17.

Figure 16 shows that the distances for the heat radiation of the pool fire, calculated by INERIS and RIVM, are very similar. This can be explained by the fact that both INERIS and RIVM use the same diameter for the pool (150 m). Besides the pool fire, INERIS also considers the possibility of a vapour cloud explosion in an area where stationing of tank cars causes congestion(16). In this case, the calculated distance to 100 mbar is 125 m from the centre of the explosion (see Figure 17). According to the Dutch methodology, the possibility of a vapour cloud explosion (VCE) should be considered for all locations (regardless of the amount of confinement and congestion). However, in SAFETI-NL a VCE only occurs if the flammable cloud has 5 GJ or more of combustion energy. For D5 this condition is not met. For F1.5 the condition *is* met and the corresponding distance to 100 mbar is 250 m.

[16] Such an incident occurred for instance in Saint-Herblain in 1991.

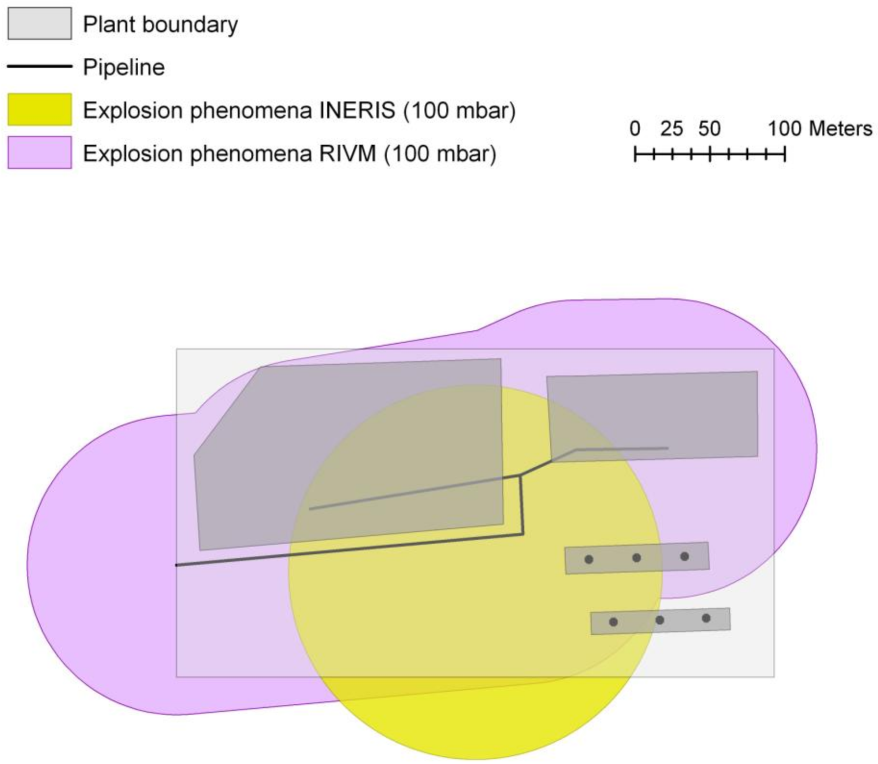

Figure 17 Explosion phenomena for the pipeline (weather type D5)

4.2.3.4 Conclusions

A first remark is that different thresholds are used by INERIS and RIVM. Whereas in French risk assessments serious injury has to be considered, Dutch QRAs for land-use planning only study lethal effects. This was already noted in section 2.5 and was not further discussed in the current section.

A first conclusion is that different scenarios and phenomena are studied. INERIS looks at tank explosions and slow kinetic phenomena (boil-over and rupture after heat impingement). These phenomena are not considered in the Dutch method. RIVM on the other hand, considers a large scale continuous release from a storage tank that is not considered by INERIS.

A second conclusion is that the assumptions for consequence modelling are different. RIVM takes into account possible bund overtopping, whereas INERIS does not. INERIS and RIVM both consider the possibility of a vapour cloud explosion after a rupture of a pipe. However, INERIS carries out detailed calculations for each congested area, whereas RIVM uses a generic approach and assumes that the possibility of a VCE can never be excluded (not even if the affected area is very open).

Lastly, the models that are used are different. INERIS uses different stand-alone models for each type of event. Many of these stand-alone models are developed by INERIS. RIVM uses a single software tool SAFETI-NL. In this software tool, all required consequence calculations are automated. It is likely that the models in

SAFETI-NL will give different outcomes than the models used by INERIS (even if the inputs were equal). However, these model differences will probably be very small in comparison with all the different input assumptions for consequence calculations.

5 Risk results

5.1 INERIS results

5.1.1 Risk matrix – permit to operate

The severity of each phenomenon was calculated using the (hypothetical) population data and the effect zones for significant lethal effect, lethal effect and irreversible effect (see section 2.1.3.3). The risk matrix is constructed by determining the severity and probability class for all dangerous phenomena. The results are presented in Table 38. These results will be used for the permit to operate process (see Table 35 for more details on the major accidents considered here).

Table 38 Risk matrix for Fictive en Tulipes (no common emergency plan)

Probability class / **Severity**	**E**	**D**	**C**	**B**	**A**
Disastrous	18				
Catastrophic			36		
Significant	7, 19, 21	1, 2, 3, 4, 5, 6, 8, 10, 13, 15, 28, 29, 30	35, 37		
Serious		9, 11, 14, 16, 17, 31, 32			
Moderate					

This risk matrix presented in Table 38 is unacceptable because of the vapour cloud fire following a pipe rupture (accident n°36). In this (fictitious) case, the permit to operate will not be delivered to the operators unless new safety measures are proposed for reducing the risk.
However, in the present case, this dangerous phenomenon affects mainly employees from the waste treatment facility. A guidance from the French ministry (see [6]) specifies that if a common internal emergency plan is set between two facilities, employees from a nearby facility will be not counted as potential persons affected by dangerous phenomena in the permit to operate process. The French ministry assumes in this case that these employees would be able to protect themselves in a better way than local population as a result of a good information and safety culture.
In the framework of this study, we assume that this common internal emergency plan will be set. In that case, the new matrix is presented in Table 39.

In this new risk matrix there are no ‘unacceptable’ major accidents. However, some of the major accident scenarios are situated in the ALARP 2 areas. Major accidents related to pipe rupture, namely the vapour cloud fire, the pool fire and the vapour cloud explosion (n°36, 35, 37), and the crude oil boil-over (n°18) are situated in ALARP 2 areas.

This means it has to be checked that all prevention and protection measures have been realised, in the limit of an acceptable cost. Concerning prevention and protection measures, the following analysis could be stated:

- no risk measures could be added to further prevent (significantly) the occurrence of the boil-over;
- some mitigation measures are available for restricting the size of the pool resulting of a pipe rupture. For example, the installation of an isolation chain (hydrocarbon detectors, alarm and closing valve procedure) should be considered. Some pipe rupture prevention barriers may be also considered.

A large number of major accidents are also situated in ALARP areas. Though the need of the improvement of the safety is less important for these accidents than for ALARP 2 accidents, it still has to be checked that they reach ALARP requirements.
If some safety improvements are considered to be relevant by the operators and the inspection in the framework of the permit to operate, the operator will have the responsibility to implement them (using his own funds).

Table 39 Risk matrix for Fictive en Tulipes (common emergency plan)

Probability class / **Severity**	**E**	**D**	**C**	**B**	**A**
Disastrous	18				
Catastrophic					
Significant	7, 19, 21	1, 2, 3, 4, 5, 6, 8, 10, 13, 15, 28, 29, 30	35, 36, 37		
Serious		9, 11, 14, 16, 17, 31, 32			
Moderate					

5.1.2 *Land-use planning: Plan de prévention des risques technologiques (PPRT)*

The PPRT is defined using aléa maps and a map of stakes together with a specific governance process. 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 aléa maps. Figure 18 presents the map of the synthesis of 'aléas' without low kinetic dangerous phenomena. For more detailed information on buildings in the vicinity of the facility, see section 3.5.
The overpressure, the thermal and the synthesis of 'aléas' with low kinetic dangerous phenomena are available in Appendix 4.

Current land-use:
On the basis of aléa maps, the recommendations for the actual land-use could be the following:

Measures which will be paid using an agreement between the state, local communities and the operator:
- expropriate the individual house of Bob the Brave which lays in the red area just south of the facility;
- the relocation of the mobile-homes field might be considered.

Measures which will be paid by owners of goods (in the limit of 10% of the value of the good):
- Conduct a study on the resistance of waste treatment facility buildings to potential overpressure effects. Depending on the outcomes of this study, the resistance of the buildings towards overpressure effects may be improved. Blast proof windows should be implemented.
- The fast food restaurant, the do-it-yourself supply store in the north-west and the bakery and the housing area of the village in the south should install blast proof windows.
- Some protection measures for roads in the vicinity of the facility may be implemented. Some recommendations may be done on the transport of hazardous substances.

Land-use planning (future):
On the basis of aléa maps, the recommendations for the actual land-use could be the following:
- Red, orange and yellow zones: ban on new constructions.
- Blue zones: extension of existing constructions possible, but these new constructions must be resistant to relevant overpressure effects and windows must be 'blast-proof'. New constructions which could increase the number of people in these areas are undesirable.
- Green zone: possibility to construct new buildings, however these buildings must limit glass surfaces and windows have to be 'blast-proof'. No public buildings difficult to evacuate should be built.
- Low kinetic zone (see Appendix 4): no public buildings difficult to evacuate should be built.

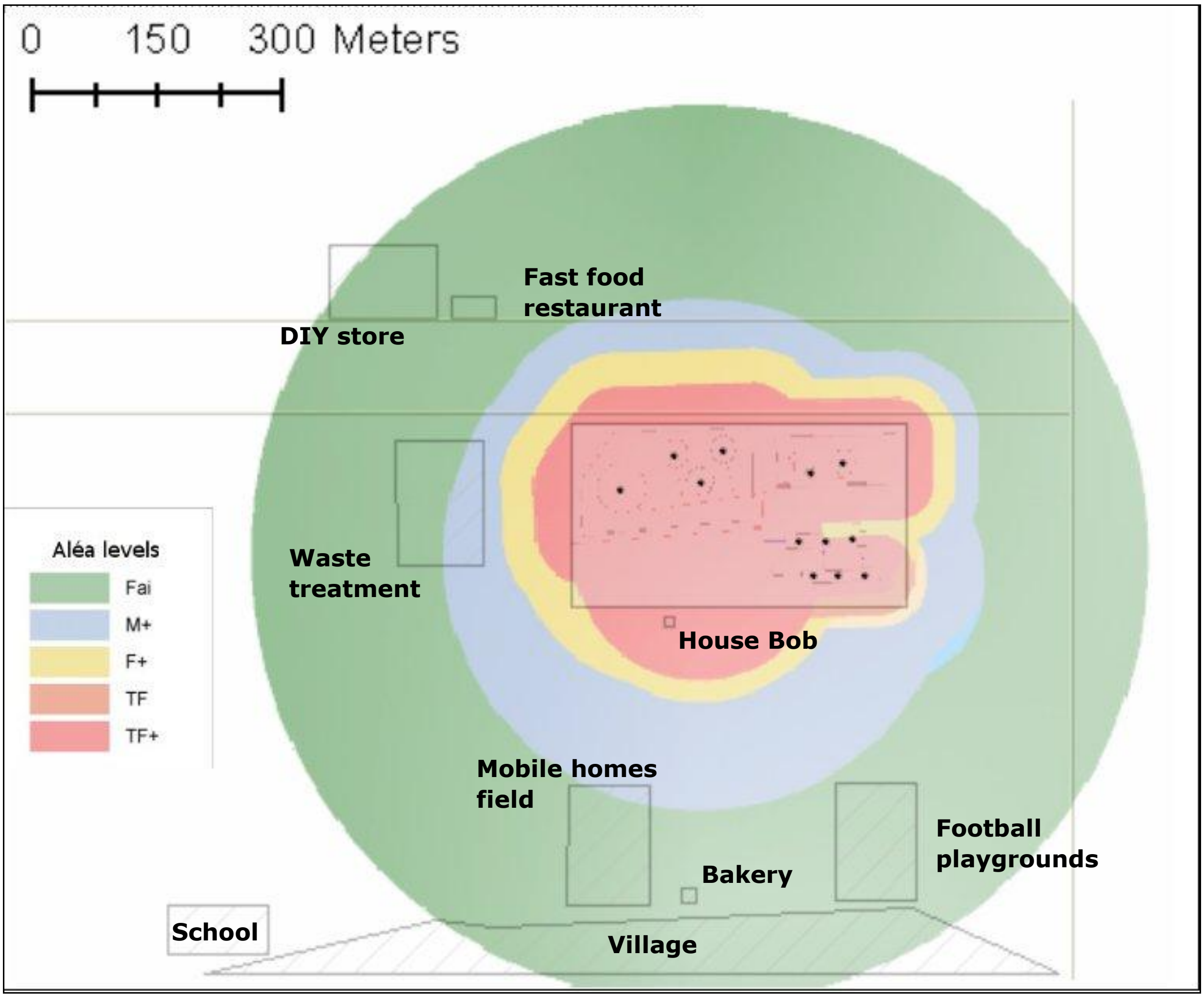

Figure 18 Synthesis of aléas without low kinetic dangerous phenomena for Fictive en Tulipes

5.2 RIVM results

The scenarios of Table 27 were put in SAFETI-NL 6.54, together with the required data for the site boundary and population and ignition sources (see section 3.5). Individual risk and societal risk were then automatically calculated in SAFETI-NL.

5.2.1 Individual Risk

The individual risk results are shown in Figure 19. Table 40 shows which scenarios contribute to the risk at the site boundary (four corner locations). Appendix 5 contains separate figures for the individual risk of the storage tanks, the pump and loading area and the pipeline.
The highest risk is centred around the pump and loading areas. In this area, the individual risk exceeds 10^{-5} per year. The scenarios leak or rupture of the pump or the loading arm have a relatively high frequency but a limited consequence distance.

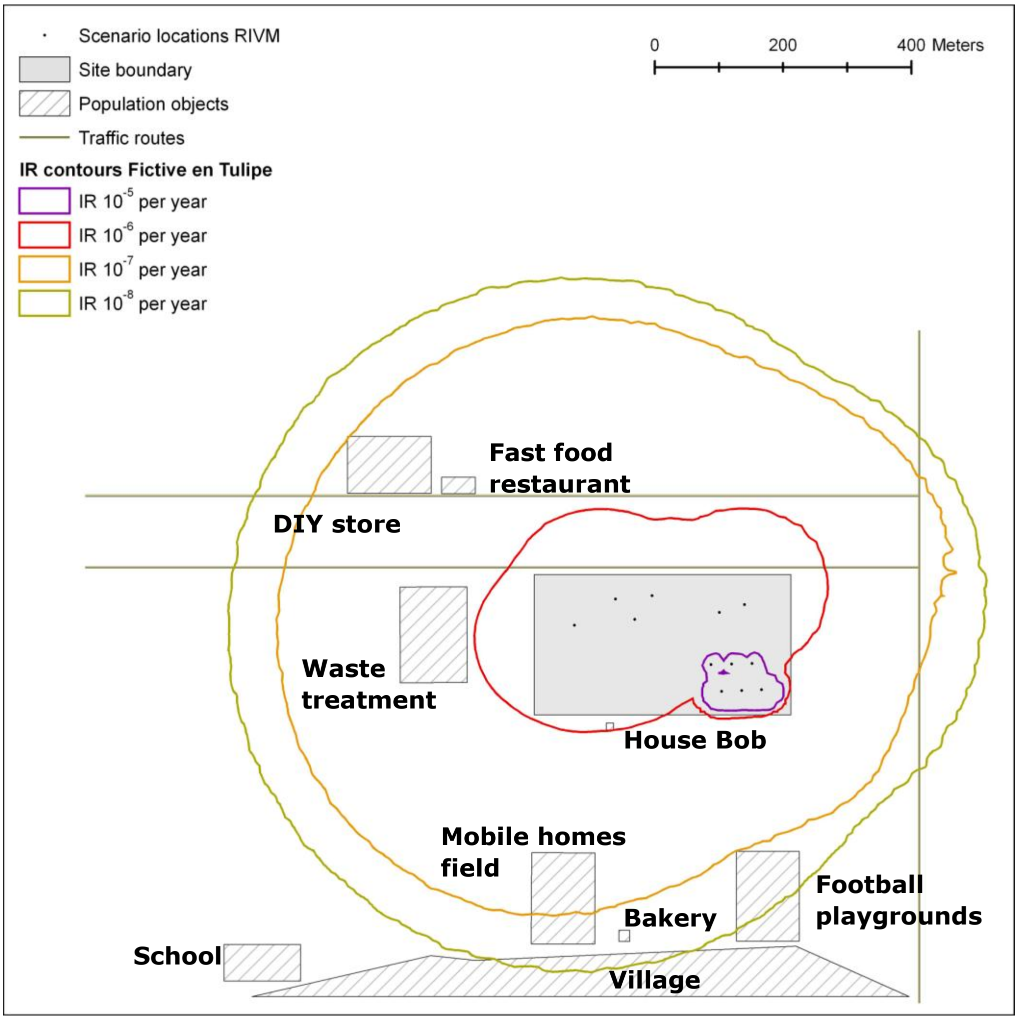

Figure 19 Individual risk contours for Fictive en Tulipes (Dutch methodology)

The IR 10^{-6} contour is located 0 to 100 m away from the site boundary. As can be seen from Table 40 and the figures in Appendix 5, the individual risk outside of the establishment is largely dominated by the 10 minutes releases from the storage tanks with class 1 flammable liquids. This is in line with Table 37, which showed that consequence distances are usually 130 m (pool fire in and around bund A) or less, with the exception of the 10 minute release scenarios for tank 1 (crude oil) and tank 5 (gasoline) (see also discussion in section 4.2.2.3). The IR 10^{-8} contour is located at a distance of 300 to 430 m from the site boundary. Beyond this distance, the probability of suffering a fatal injury as a consequence of an incident at the depot is very limited.

One single house is located within the IR 10^{-6} contour. According to Dutch legislation, isolated houses are not regarded as 'vulnerable objects' but as 'objects of limited vulnerability'. As a consequence, the expropriation of the house of Bob the Brave is not necessitated.

The IR 10^{-6} contour needs to be implemented in the zoning plan of the local community. New vulnerable objects within the 10^{-6} contour are intolerable. New objects of limited vulnerability within the 10^{-6} contour are highly undesirable and will only be accepted if there are pressing reasons for the development at stake.

These limitations on future land-use should be reflected by restrictions in the zoning plan.

Table 40 Contributions of scenarios to individual risk at site boundary

	Total risk / risk contribution
North-west corner (upper left)	3.3×10^{-6} per year
catastrophic rupture tank 1	56.8%
10 minute release from tank 1	38.2%
10 minute release from tank 5	4.5%
rupture of the pipeline	0.5%
North-east corner (upper right)	2.1×10^{-6} per year
10 minute release from tank 5	67.6%
10 minute release from tank 6	15.5%
10 minute release from tank 1	13.8%
rupture of the pipeline	1.5%
leak from the pipeline	1.5%
South-east corner (lower right)	5.3×10^{-7} per year
10 minute release from tank 5	60.3%
10 minute release from tank 1	39.7%
South-west corner (lower left)	1.2×10^{-6} per year
10 minute release from tank 1	68.8%
catastrophic rupture tank 1	17.9%
leak from the pipe line	6.5%
rupture of the pipeline	4.8%
10 minute release from tank 5	2.0%

5.2.2 *Societal risk*

The societal risk results are shown in Figure 20. The maximum number of casualties is 40 and the corresponding frequency is 3×10^{-9} per year. According to the calculations, release scenarios in the pump and loading areas do not lead to casualties outside the establishment. A leak or rupture of the pipeline may affect the house of Bob the Brave (flash fire or explosion) and the waste treatment facility (explosion only). The corresponding number of casualties is very limited (maximum 2). Societal risk is therefore dominated by the release scenarios for the storage tanks, more particularly the 10 minutes scenarios for tank 1 (crude oil) and tank 5 (gasoline). The worst possible incident is a 10 minute release with low wind speed during day time (D1.5). For this case, the flammable cloud may reach the fast food restaurant (15 persons present) and the front of the do-it-yourself supply store (150 persons present). A 10 minute release during night time with stable weather conditions (F1.5) produces the largest consequence distances, but gives a limited amount of casualties because most population objects in the vicinity of the depot will be empty during night hours.

As discussed in section 2.3.2.2, societal risk is only evaluated for new situations (a request for a change in the permit or a request for a change in the zoning plan). In order to prevent an uncontrollable increase of risk, the local authorities need to implement the maximum effect zone (see Figure 21) in the zoning plan. New developments in this zone can only be achieved if the increase in societal risk is assessed with reference to alternatives to the proposed development, and is subsequently accepted by the competent authority in a transparent way (see section 2.3.2.2). However, as the societal risk is at least one order of magnitude below the guide values, it is expected that most local authorities would tolerate a small increase in activity around the facility, if sufficient means for relief and self-rescue exist. For example, the development of small enterprises or small industrial activities may be regarded as acceptable when the accessibility of these objects for emergency response units is good and if the employees and associated persons have sufficient means for sheltering and evacuation.

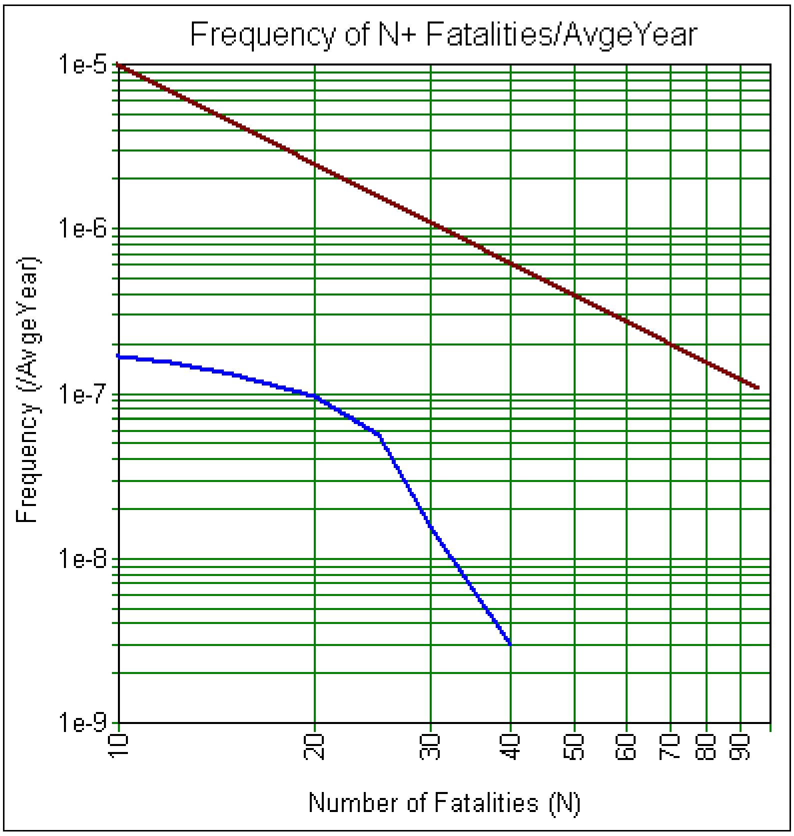

Figure 20   FN-curve for Fictive en Tulipes (Dutch methodology)

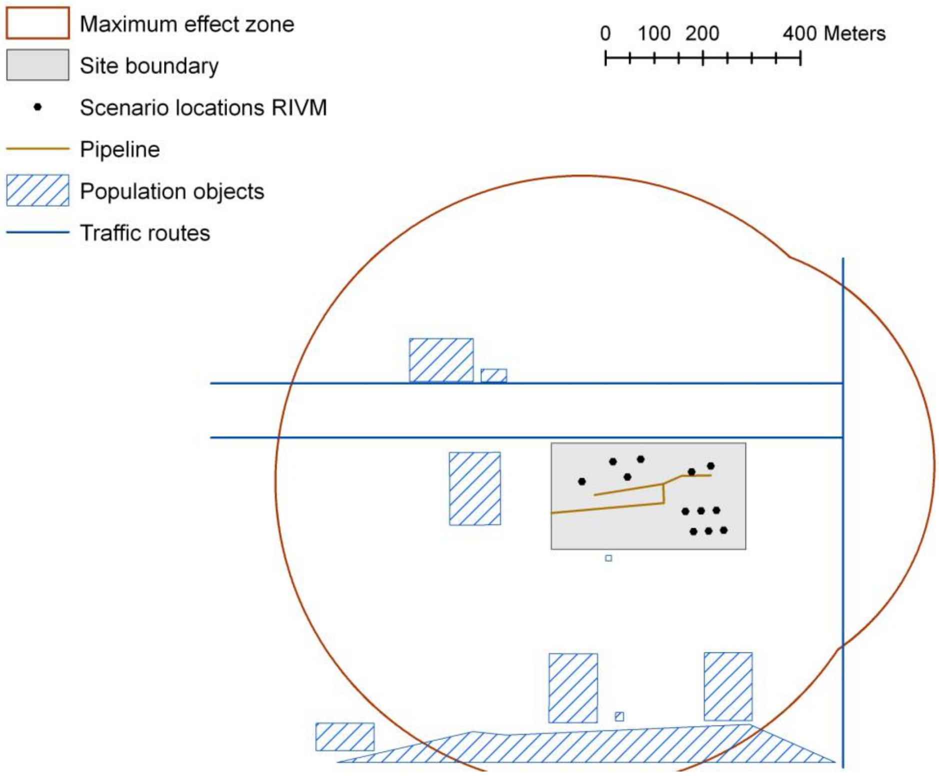

Figure 21 Maximum effect zone (to be used for Dutch land-use planning)

5.2.3 *Discussion*

As was observed in the previous sections, the outcomes for individual risk and societal risk are not expected to give large problems for the permit to operate. It is desirable to expropriate the house of Bob the Brave, but this is not necessitated by the legislation currently in use in the Netherlands.
If there had been vulnerable objects within the IR 10^{-6} contour, or if the outcome for societal risk was unacceptable for the local authorities, a reduction of risk would be required. This could either be achieved by reducing the amount of activities in the vicinity of the site, or by taking additional measures at the depot. The latter is often cheaper but poses a problem for the Dutch risk calculation methodology, because the frequencies to be used are generic and little is known about the root causes underneath these generic frequencies ([26]). For example, the probability of a 10 minute release from a single containment atmospheric storage tank is 5×10^{-6} per year, regardless of the design of the tank, the products contained in the tank and the amount of alarms added to the tank. Frequency reducing safety measures can often not be awarded by lower frequencies and the outcomes for risk calculation will not be affected by such additional safety measures. The difficulty to award the effectiveness of safety measures in a frequency reduction for the QRA is one of the most important disadvantages of the current Dutch methodology and significant effort is made to improve this situation.

The question is thus: how do specific measures relate to generic scenarios and what frequency reduction is appropriate when the measure is applied? A study on this topic was recently carried out for atmospheric storage tanks ([26]). The idea is to first relate each generic QRA scenario to a set of specific root causes. This requires some expert judgement. Subsequently, it has to be determined to which extent each of the root causes contributes to the generic scenario. The third step will be to distinguish different types of installations and determine which root causes are relevant for each of the installation types that is distinguished. This will provide a more specific frequency for the generic scenario. For example, instead of one generic frequency for a single containment atmospheric storage tank containing flammable or non-flammable liquids, a distinction can be made between single containment atmospheric storage tanks containing flammable liquids and single containment atmospheric storage tanks containing non-flammable liquids. The last step will then be to determine the effectiveness of the barrier on the root cause and to calculate a further reduction in the frequency.

Example
In a recent database analysis (see [26]), 54 incidents were found that had or could have had a possible lethal effect outside the establishment. Using expert judgement, 28 of these incidents were linked to the catastrophic rupture scenario, 17 were linked to the 10 minute release scenario and 9 were linked to the leak from a 10 mm diameter orifice. From the 17 incidents that were linked to the 10 minute scenario, 7 incidents were overfill incidents. Suppose that an operator wants to reduce the risk of overfilling by installing an additional and independent overfill protection (alarm and valve) with a probability of operation on demand of 90%. This operator would then be awarded with a reduction in the total frequency for the 10 minute scenario of 37% (90% × 7/17).
However, the analysis also showed that many incidents are related to flammable products. It is therefore arguable that the generic failure frequency of an atmospheric tank containing non-flammable liquids is equal to the generic failure frequency of an atmospheric tank containing flammable liquids. If the average failure frequency for both types of tanks remains equal (5×10^{-6} per year), the generic failure frequency for a tank with non-flammable liquids should be below 5×10^{-6} per year and the generic failure frequency for a tank with flammable liquids should be above 5×10^{-6} per year.
In other words, even if the methodology would be improved in such a way that frequency reducing safety measures can be rewarded (for example with 37%), it is questionable whether the final frequency to be used for a storage tank containing flammable liquids with additional overfill protection, will be lower than the frequency that is currently used. However, the new method would produce more accurate results.

5.3 Comparison of results

5.3.1 Permit to operate

In the French regulatory framework, the permit to operate for an existing installation could be refused to an operator if the risk matrix shows an unacceptable situation and if no additional safety measures are proposed. In the Dutch regulatory framework an existing facility with a valid permit has the right

to operate as long as the activities on the facility are not altered[17]. The French risk matrix shows an ALARP situation if a common emergency plan is defined with the nearby facility. An assessment of the societal risk was carried out using the Dutch methodology. The results will probably be acceptable for the responsible authorities.
Also, the French regulation imposes to operators that may have accidents in the ALARP areas, to prove that the level of safety in their facility is as low as reasonably possible. In the present fictitious case, it could be asked to the operator to improve its safety levels (mainly for major accident scenarios related to pipe rupture). The Dutch regulation would not ask for additional safety measures if the construction, operation, inspection and maintenance of the installations are in accordance with current industrial norms.

5.3.2 Land-use planning

Figure 22 presents a map that shows French aléa levels together with Dutch individual risk contours.

Outcomes for the actual land-use
Both methodologies underline a problem with the single isolated house of Bob the Brave that lies just south of the facility. However the tools which will be used in order to solve it, will be different.
In the French regulatory context, this individual house will be expropriated through the PPRT. The cost of this measure will be divided using an agreement between the state, the local communities and the operators. In the Dutch regulatory context, the presence of a single isolated house formally does not require the expropriation or the relinquishment of the house. Nevertheless, the presence of this house will be regarded as undesirable. Presuming that the facility has a valid permit to operate, local authorities will then be in charge of the decision to expropriate this house, on its own fund, or not.
The PPRT may implement additional measures for buildings in blue and green areas. These measures concern the resistance of the structure and the windows with regard to overpressure effects. Within the Dutch context of societal risk assessment, safety measures for buildings could be considered. However, as the societal risk is well below the guide values, it is not likely that the competent authority would demand for such measures.

Outcomes for the land-use planning:
Concerning the land-use planning, the elements to be considered are mainly the Dutch IR 10^{-6} contour and the French yellow aléa area. These two zones define the areas where new constructions are banned.

Figure 22 shows a remarkable match of these two elements at most locations. The match is surprising because of the large differences between the two methodologies for evaluating the risk. The first explanation for the match is the importance of the pool fire in the risk of areas close to the facility. The assessment of the risk related to this dangerous phenomenon is comparable

[17] In specific cases public authorities can buy-out the permit holder.

between the two methodologies. The second explanation is that differences in methodologies balance out.

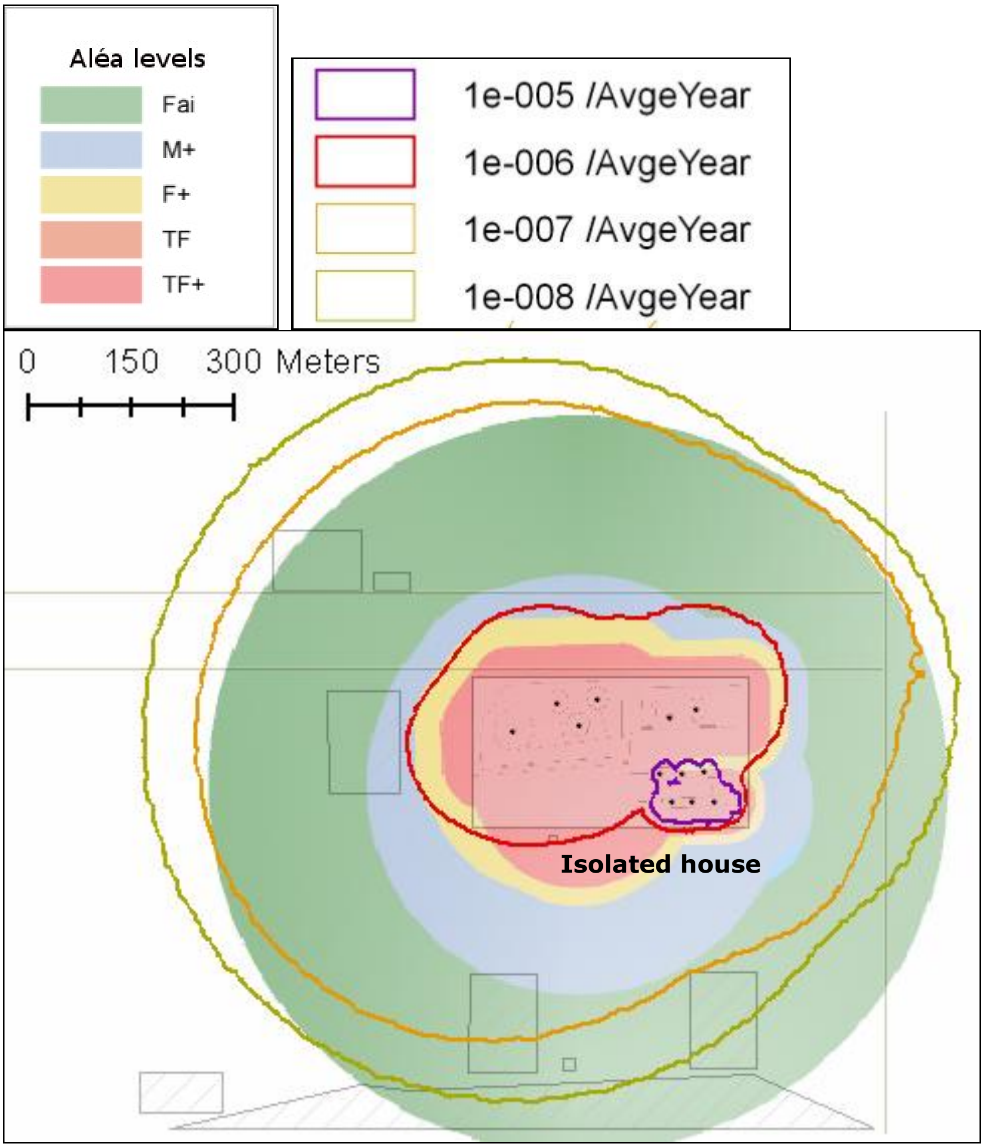

Figure 22 Dutch individual risk contours and French aléa levels for Fictive en Tulipes

Some Dutch scenarios with large consequence distances are not taken into account in the INERIS methodology (mainly the tank ruptures and the 10 minutes releases). Although these scenarios have a very low probability of occurrence, they have a significant influence on the results. On the other hand the INERIS methodology studies the tank explosion scenario which is not considered in the Dutch methodology. Furthermore, the French thresholds used for expressing thermal and overpressure effects are more restrictive than the Dutch probit function.

A detailed analysis of the map above shows that the Dutch IR 10^{-6} contour and French ban on new construction zones vary in three main areas: in the north-east, in the south-east and in the south of the facility.

- North-east of the facility, the Dutch IR 10^{-6} contour is slightly more distant than the French yellow area. The risk in this area is dominated by scenarios related to bund B. The main reason of the difference is that the consequence distances that are calculated for the INERIS scenarios are smaller than the consequence distances calculated for the RIVM scenarios. RIVM presumes a larger pool size for the rupture of a tank (150% of the bund size) and also considers a large continuous release (the 10 minute scenario for tank 5) that gives a vapour cloud well outside the bund. INERIS calculates a pool fire in the bund, and a tank explosion, but all these scenarios have a limited effect distances.
- In the south-east, close to the loading area, the French yellow contour is almost identical to the Dutch IR 10^{-6} contour. In the INERIS methodology loading areas and pump areas are considered as ‘obstructed’ areas. The corresponding vapour cloud explosions give effect distances that are slightly larger than the Dutch distances that are derived from generic assumptions.
- South of the facility, the French yellow contour is more distant than the Dutch IR 10^{-6} contour. The reason of this difference is again related to vapour cloud explosions. Following the INERIS methodology, an obstructed area was defined at the south-west side of the facility where stationing of tank cars occurs. The presence of this obstructed area, combined with a very large release from the pipe and a low probability of occurrence give a very large high aléa zone and therefore a large area with land-use planning restrictions in the south of the facility. In the Dutch framework, an explosion following rupture of the pipeline only occurs for weathers D1.5 and F1.5, and the cumulative frequency is not large enough to effect the location of the IR 10^{-6} contour.

In more distant areas, the French PPRT will probably introduce some land-use restrictions in blue areas, green areas and low kinetic areas. These restrictions will concern mainly the design and construction of buildings and some restrictions on the construction of public buildings. Such restrictions are not applied in the Dutch regulation for two main reasons:

- In the Dutch regulatory context, land-use planning is based on lethal effects: non-lethal consequences, comparable to the French irreversible and indirect thresholds, are not taken into account for land-use planning.
- The Dutch regulation does not take into account low kinetic scenarios for land-use planning. It is conceived that the population in the surroundings of the facility will have enough time to evacuate the area prior to the occurrence of the low kinetic event.

On the other hand, the maximum effect zone for lethal effects (Figure 21) is likely to be implemented in the zoning scheme (Dutch context). In this zone, new constructions can only be built after consultation of the fire department and subsequent approval for construction from the community council. The size and location of this maximum effect zone is very similar to the French green area (Figure 18).

6 Conclusions

In this report, the French and Dutch contexts for determining hazardous areas in the vicinity of a Seveso company were compared. For this comparison, risk calculations for a fictitious storage of flammable liquids were carried out. These calculations were performed by RIVM using the Dutch methodology and by INERIS using the INERIS methodology in the context of the French regulations. The methodologies have been compared at three levels:

- the selection of scenarios and their frequencies;
- the results of effect distance calculations;
- the consequences for the permit to operate and the land-use planning in the vicinity of the facility.

The main conclusion is that many differences exist between these two methodologies. The most important differences are summarised below:

1. Methodology: In the Dutch regulatory context, the methodology to be used is prescribed, whereas in the French regulatory context the methodology to be used is optional (within a framework of guidance provided by the ministry on environment and technical working groups for specific type of facilities). The Dutch ministry decided that it was important to have one unified method for performing risk calculations. As a result all scenarios, frequencies and other necessary assumptions for risk calculation are documented in a 'reference manual'. Companies can only deviate from these default assumptions if they can underpin their choices with persuasive evidence (to be approved by the competent authority or the minister, depending on the significance of the deviation). In the French regulatory context, companies are allowed to choose their preferred methodology for risk calculations. The scenarios to be used in the risk assessment are obtained from the risk analysis in the safety report, for which different methods can be used (for example HAZOP or FMECA). However, industrialists have to prove the relevance of the choices made in the safety report. In the current study, INERIS made use of bow-tie diagrams that take into account initial event frequencies and failure probabilities of prevention barriers.
2. Scenarios: The Dutch context strives to obtain a limited list of generic scenarios that is sufficiently representative for the overall risk imposed by a facility, while the French context strives to obtain a list of scenarios that is exhaustive for all relevant accidents. As a result, the obtained sets of scenarios are different. For example, the Dutch methodology takes into account a release of the entire contents of a tank in ten minutes whereas INERIS does not. On the other hand INERIS takes into account tank explosions for fixed roof tanks whereas the Dutch methodology does not.
3. Frequencies: Concerning frequencies, the Dutch methodology uses pre-defined and standardised frequencies for generic types of equipment. These frequencies have been defined using literature researches. It is assumed that equipment is constructed, maintained, operated and inspected in accordance with current industrial norms. The specific design and construction of the equipment and the presence of optional additional safety

measures (not required by the industrial norms), are currently not relevant for the frequencies to be used in the QRA. The INERIS methodology on the other hand, allows using lower or higher frequencies depending on the prevention barriers implemented in the facility and the frequency of initial events. These frequencies are defined using a process involving expert judgements.

4. Damage criteria: In the Netherlands, the main criterion for land-use planning is the probability of lethality of people exposed to dangerous phenomena. This value is assessed using a probit function for the heat radiation of jet fires and pool fires and fixed thresholds for flash fire and explosion effects. In France, the criteria at the basis of the land-use planning is the number of people exposed to three predefined intensities of effect for thermal radiation and four predefined intensities of effect for overpressure. Some of these predefined intensities aim to be representative for irreversible and indirect effects on human beings.
5. Consequence outcomes: In order to compare the results of effect distance calculations, footprint maps for 10 kW/m^2 heat radiation and for 100 mbar overpressure have been drawn for several parts of the facility. These maps show the distances which are expected according to both methodologies for a pre-defined level of effect. Of course, minor differences in calculated effect distances were expected because of the use of different effect models. However, the analysis of these maps showed important variations that were caused by differences in hypotheses underlying the consequence calculations. The most important differences relate to the calculated effects of vapour cloud explosions.
6. Risk outcomes: from a very general point of view, both methodologies identified the same areas with a 'high risk' and a 'low risk'. However the assumptions that lie underneath these outcomes are different (see above) and the consequence for the permit to operate and for land-use are different as well (see below).
7. Permit to operate: In the Dutch regulatory context, outcomes of the QRA are only used for granting (or refusing) a permit if the activity is new (new permit request) or if there is a change of activities (revision of the permit). If, as was the case in the current study, there is no change in activities, the current permit cannot be withdrawn as a result of the QRA outcomes. In the French regulatory framework, the risk matrix is used for the delivery (or refusal) of the permit, and also for continuation (or discontinuation) of the permit. In the present case, the permit would be delivered (continued) only if the operator will define a common emergency plan with the waste treatment facility nearby. Moreover, the situation would be considered as 'ALARP' and additional prevention and protection measures could be implemented in order to reach the 'as low as reasonably practicable' requirements.
8. Current land-use: Concerning the actual land-use, the French PPRT will expropriate one house and probably impose some improvements in the resistance of windows and buildings in the vicinity of the facility. The Dutch local authorities will acknowledge that the presence of a house within the IR 10^{-6} contour is highly undesirable, but there is no formal obligation for expropriation. Improvements in the resistance of windows and buildings can

be desired within the scope of the duty to account for the societal risk. However, as the societal risk is quite low in this case, it is unlikely that expensive constructive measures would be requested.

9. Future land-use: The results of the 'aléa' maps and the iso-risk contours show that new constructions would be banned in France and in the Netherlands in roughly the same areas. However, the French PPRT would probably introduce some additional restrictions on the construction of public buildings which are hard to evacuate and on the design of new houses and buildings (with regard to walls and windows resistance to overpressure). In the Dutch legislative context, the safety measures to be taken for new constructions do not directly depend on the outcomes of the QRA. Instead the fire brigade must be consulted for the requirements for new constructions within the maximum effect zone.

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Vocabulary

ALARP	As Low As Reasonably Practicable.
Aléa	Combination of the probability of occurrence of an event and the severity of its effect.
Boil-over	Fireball ejected from a hydrocarbon tank due to the violent vaporization of a thin layer of water located at the tank bottom under layers of hydrocarbons. This vaporization occurs when the descending heat wave from the burning hydrocarbons at the top reaches the water layer at the bottom.
Class 1 flammable liquids	Highly flammable liquids as defined in the EU Seveso II Directive, Annex I, part 2, category 7a/b. In other words, liquids with a saturated vapour pressure below 100 kPa at 35 °C and a flash point between 0 and 21 °C.
Class 2 flammable liquids	Flammable liquids as defined by the EU Seveso II Directive, Annex 1, part 2, category 6. In other words, liquids with a saturated vapour pressure below 100 kPa at 35 °C and a flash point between 21 and 55 °C.
Class 3 flammable liquids	Flammable liquids with a flash point between 55 and 100 °C.
Class B flammable liquids	According to the French ICPE (Installations Classées pour la Protection de l’Environnement) classification: Flash point below 55 °C and saturated vapour pressure below 100 kPa at 35 °C.
Class C flammable liquids	According to the French ICPE (Installations Classées pour la protection de l’Environnement) classification: Flash point larger than or equal to 55 °C and smaller than 100 °C.
Fire fed leak	Fire that occurs when a leak of flammable liquids at ambient temperature and negligible overpressure is ignited.
Flash fire	Fire that occurs when a flammable cloud is ignited.
FMECA	Failure Mode, Effect and Criticality Analysis (also Failure Mode and Effects Analysis, FMEA). Technique to identify failure modes of a system and their consequences. In addition the technique provides measures to prevent such failures.
Fire fed leak	Fire that occurs when a leak of flammable liquids at ambient temperature and negligible overpressure is ignited.
FN-curve	A frequency-fatality plot, showing the cumulative frequency (F) of events with N or more fatalities.

Free field approach	Conservative assumption that is used in the Dutch risk calculation methodology. The assumption is that flammable clouds will always ignite if they move beyond the site boundary. Furthermore, the flammable cloud is assumed to ignite at maximum cloud size.
HAZOP	Hazard and Operability Analysis. Technique that identifies in a systematic and qualitative manner foreseeable failures of equipment due to deviations in process or operation, and the consequences of such deviations.
Individual Risk (IR)	Probability that during one year an imaginary person that resides continuously at a specific location dies as a consequence of an incident involving an activity with hazardous substances. Also refered to as Location-based Risk or Locational Risk.
IenM	Dutch Ministry for Infrastructure and the Environment (in Dutch: Ministerie van Infrastructuur en Milieu).
INERIS	Institut National de l’Environnement Industriel et des Risques (National Institute on Industrial Environment and Risks).
Jet fire	Fire that occurs when a vapour, aerosol or two-phase jet is ignited.
Kinetic	The term ‘kinetic’ refers to the time scale of the incident and the time needed for evacuating local populations. Fast kinetic phenomena involve dangerous phenomena that may occur rapidly after the beginning of the central event. Slow kinetic phenomena are phenomena that only occur after some delay.
MEDDTL	French Ministry for Ecology, Sustainable Development, Transport and Housing (in French: Ministère de l'Écologie, du Développement Durable des Transports et du Logement).
Pool fire	Fire that occurs when a pool of flammable liquids is ignited.
PPRT	Plan de Prévention des Risques Technologiques (Technological Risk Prevention Plan).
QRA	Quantitative Risk Analysis.
RIVM	Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and the Environment).
SAFETI-NL	Software package prescribed by Dutch legislation for QRA calculations involving establishments using, storing and/or producing significant amounts of hazardous substances.

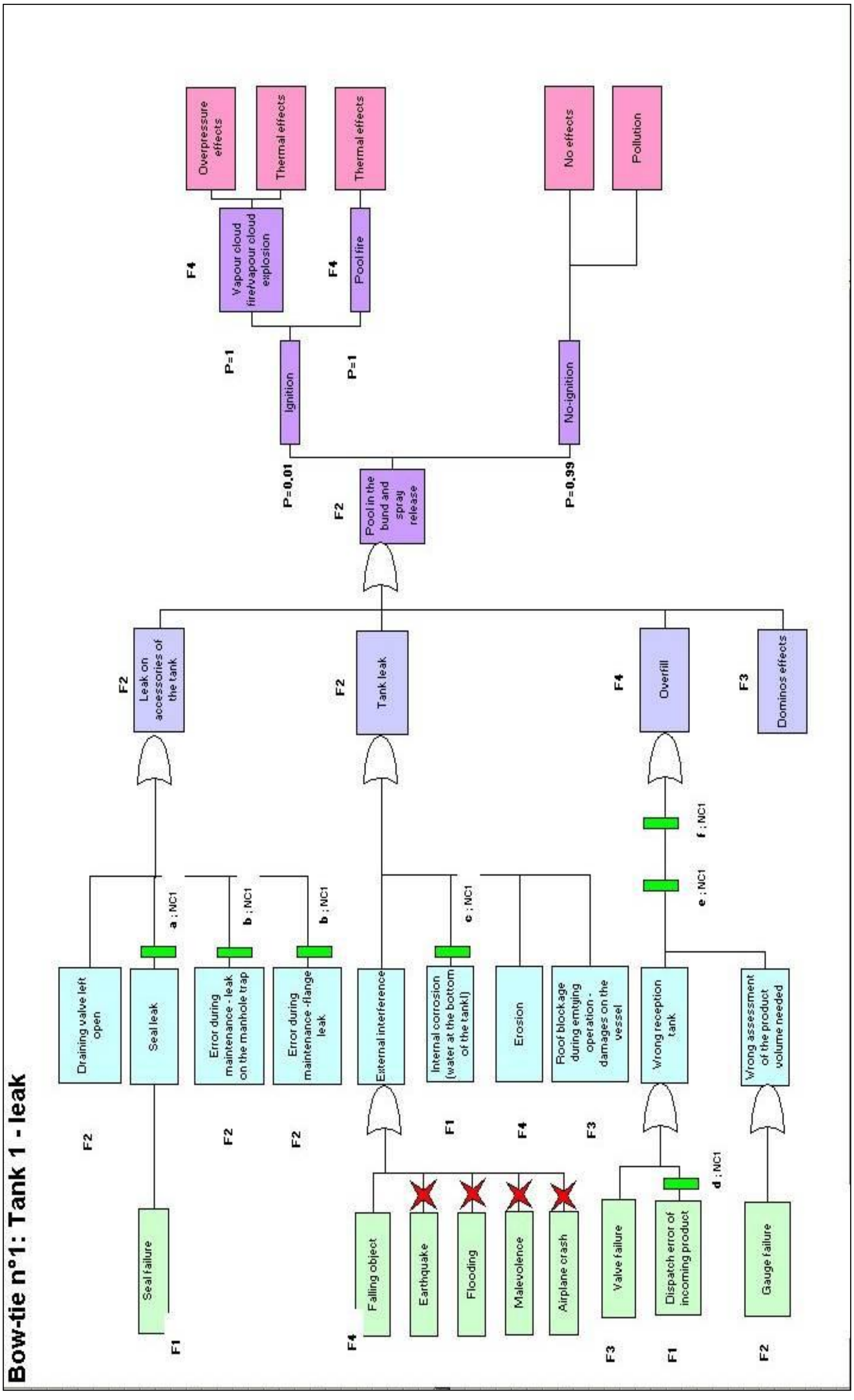
Seveso II	European Union Council Directive 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances.
Societal Risk (SR)	Probability that during one year N or more persons die in a single incident involving an activity with hazardous materials.
Thin-layer boil-over	Milder form of a boil-over, may occur when the fractions of the hydrocarbon mixture have a limited range in density.
Third party risk	A generic term for the risk that industries or activities impose on third parties. Related to industries using hazardous substances, third party risk involves the risk for people around the industry to become a victim of an accident with these chemicals at the industry.
VCE	Vapour cloud explosion; overpressure effects resulting from ignition of a fuel and air mixture, usually due to partial confinement and/or congestion of the cloud.
VCF	Vapour cloud fire, also referred to as 'flash fire'.
VROM	Former Dutch Ministry of Public Housing, Spatial Planning and the Environment (in Dutch: Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer).

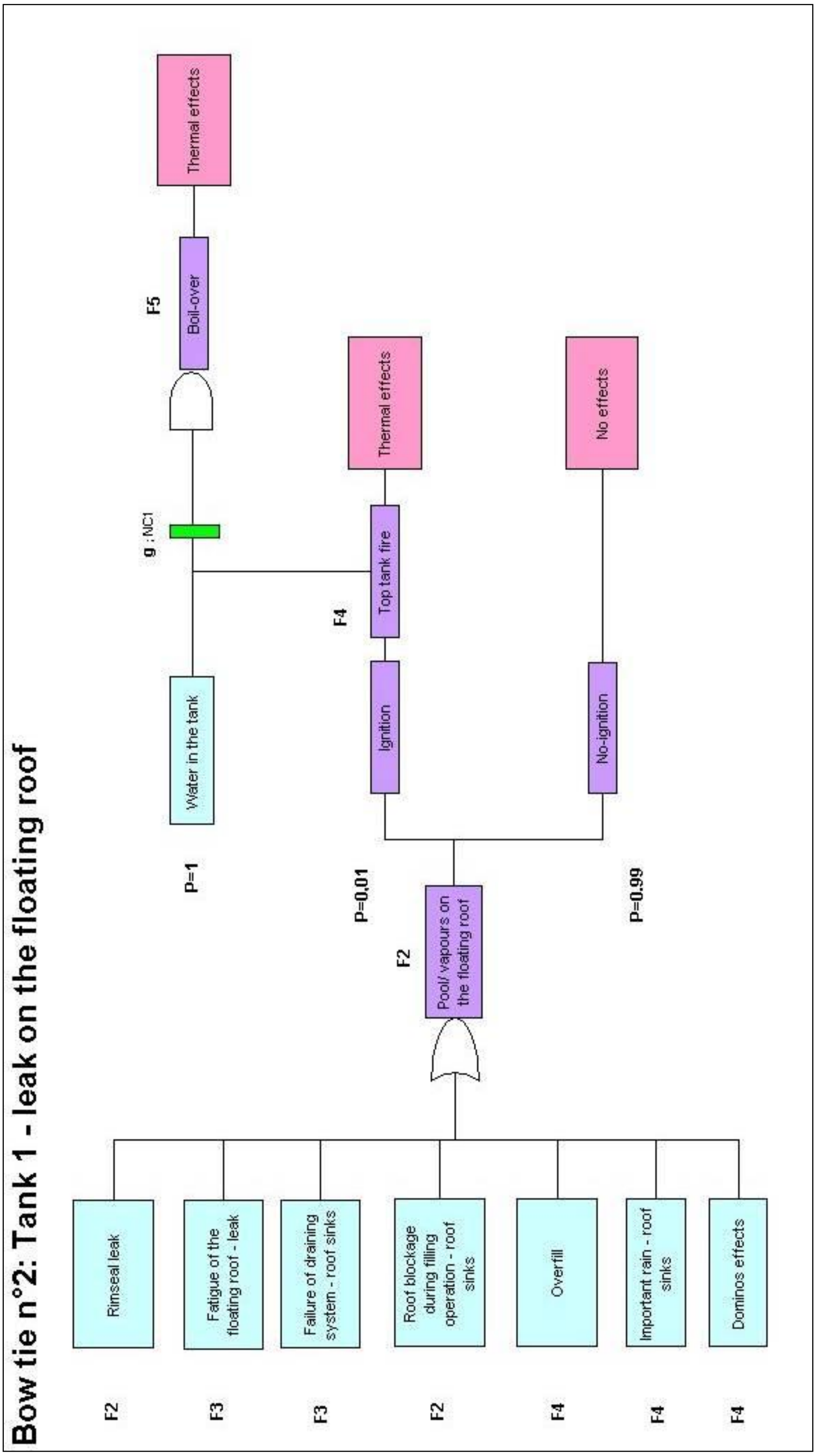
Appendix 1 Bow-tie diagrams

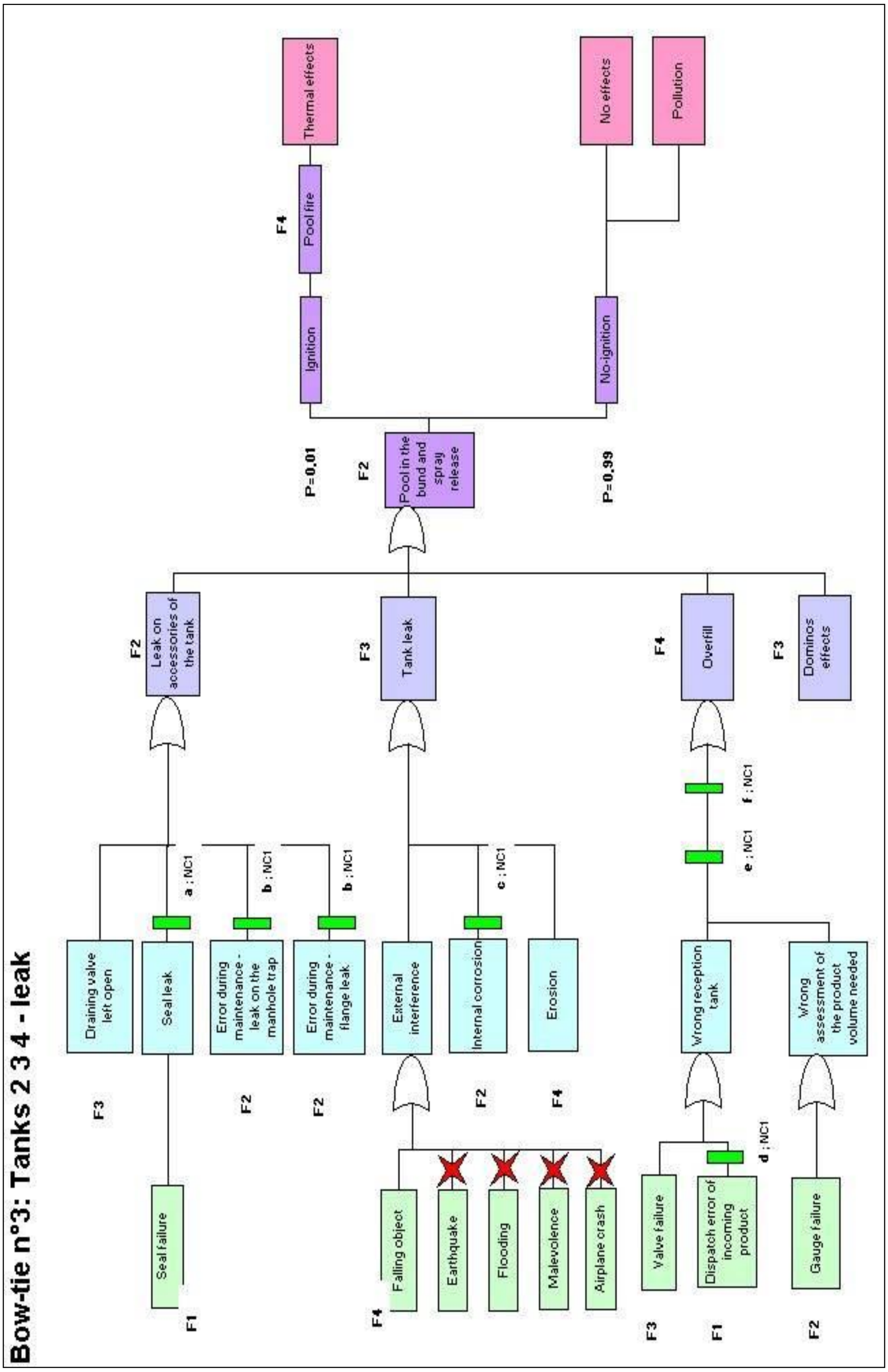
In this appendix the Bow-tie diagrams for the INERIS methodology are presented:

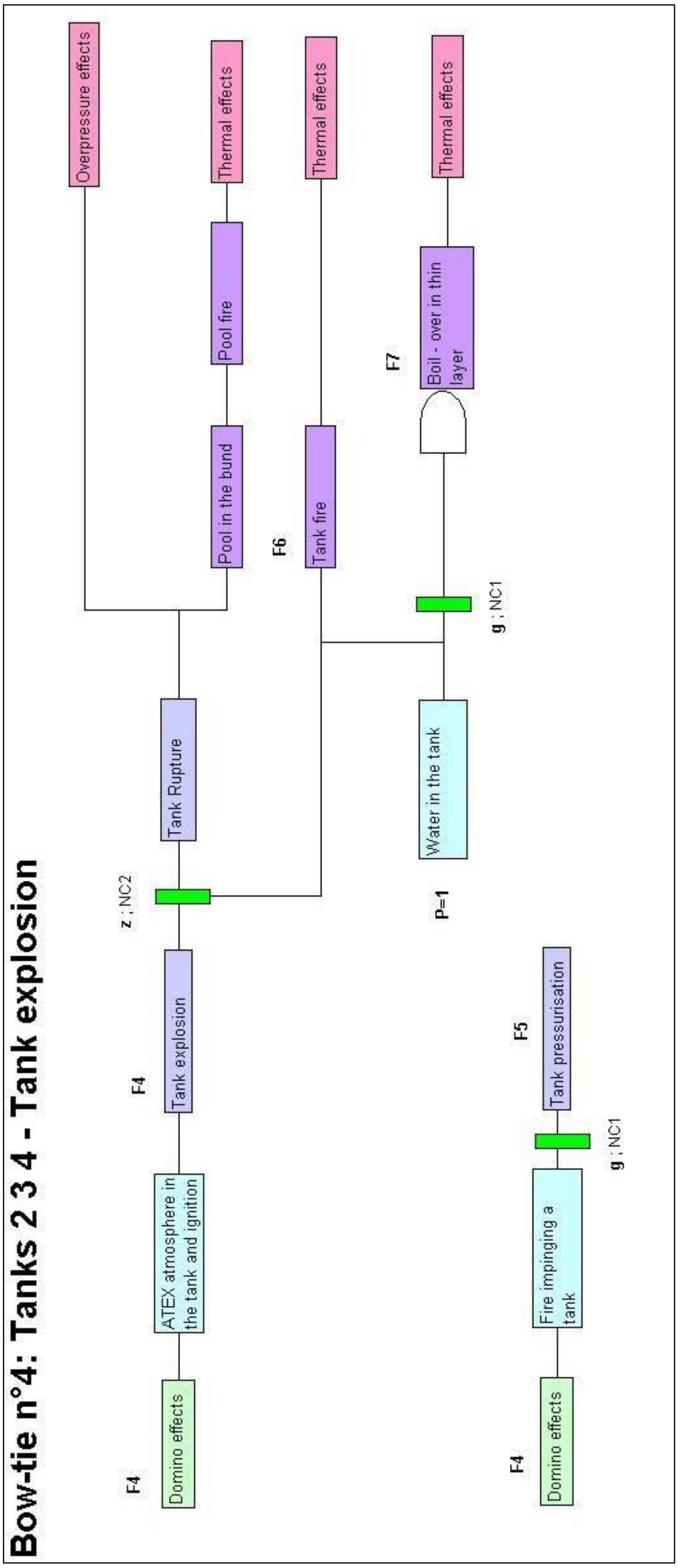
- Bow-tie n°1: Tank 1 - leak
- Bow-tie n°2: Tank 1 - leak on the floating roof
- Bow-tie n°3: Tanks 2, 3, 4 - leak
- Bow-tie n°4: Tanks 2, 3, 4 - tank explosion
- Bow-tie n°5: Tank 7 - leak
- Bow-tie n°6: Tank 7 - tank explosion
- Bow-tie n°7: Tank 5 - leak
- Bow-tie n°8: Tank 5 - leak on the floating roof
- Bow-tie n°9: Tank 6 - leak
- Bow-tie n°10: Tank 6 - tank explosion
- Bow-tie n°11: Loading post (loading from the bottom of the tank) - leak
- Bow-tie n°12: Loading post (loading from the top of the tank) - leak
- Bow-tie n°13: Pumps - leak
- Bow-tie n°14: Pumps - rupture
- Bow-tie n°15: Pipe 12” - leak
- Bow-tie n°16: Pipe 12” - rupture

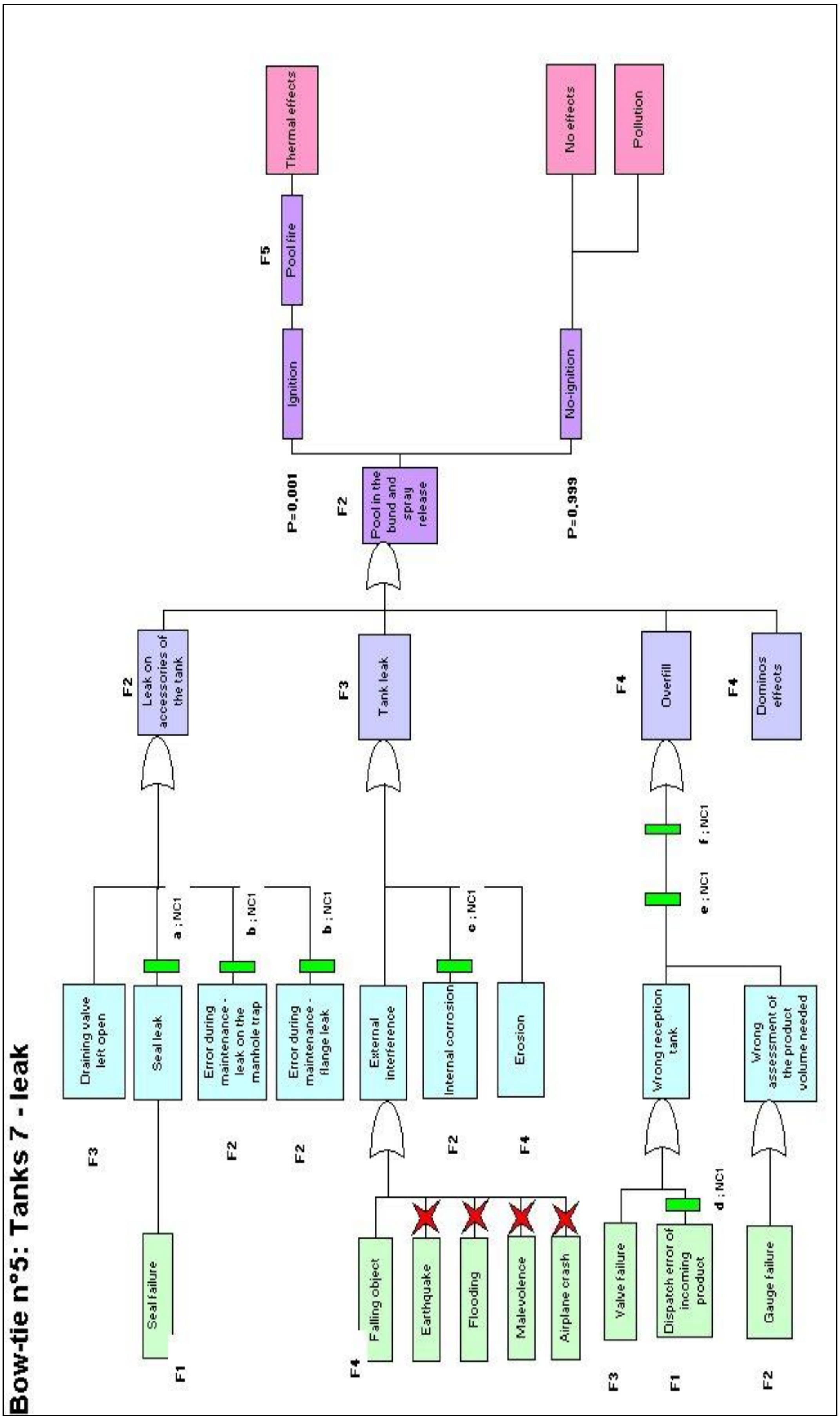
In these diagrams, barriers are indicated by a single letter. A description of these barriers is provided at the end of this appendix.

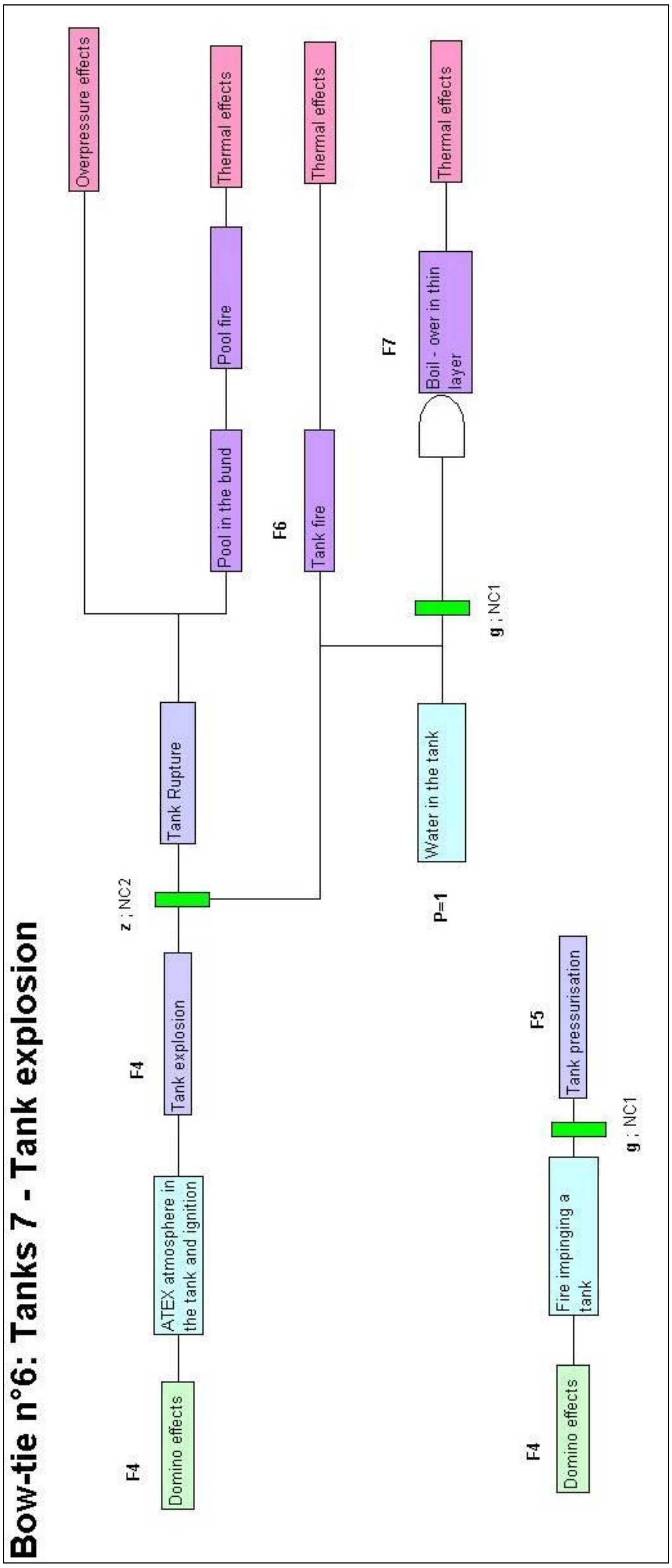

Bow-tie n°1: Tank 1 - leak
Seal failure
F1
Seal leak
Draining valve left open
F2
a ; NC1
Error during maintenance - leak on the manhole trap
F2
b ; NC1
Error during maintenance - flange leak
F2
b ; NC1
Leak on accessories of the tank
F2
Falling object
F4
Earthquake
Flooding
Malevolence
Airplane crash
External interference
Internal corrosion (water at the bottom of the tank)
F1
c ; NC1
Erosion
F4
Roof blockage during emtying operation - damages on the vessel
F3
Tank leak
F2
Valve failure
F3
Dispatch error of incoming product
F1
d ; NC1
Wrong reception tank
e ; NC1
f ; NC1
Gauge failure
F2
Wrong assessment of the product volume needed
Overfill
F4
Dominos effects
F3
Pool in the bund and spray release
F2
P=0,01
Ignition
P=1
Vapour cloud fire/vapour cloud explosion
F4
Overpressure effects
Thermal effects
P=1
Pool fire
F4
Thermal effects
P=0,99
No-ignition
No effects
Pollution

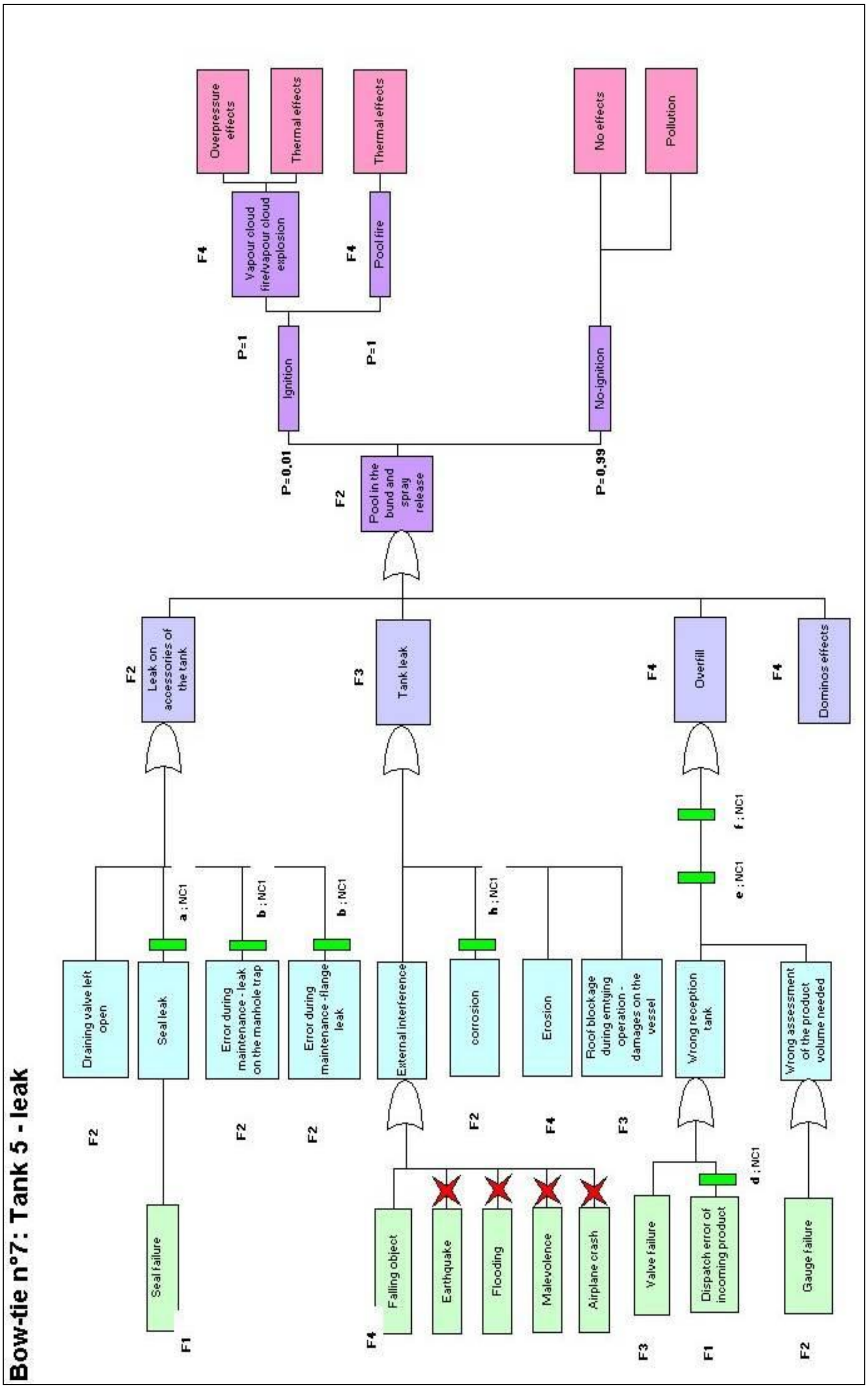

Bow tie n°2: Tank 1 - leak on the floating roof
F2
Rimseal leak
F3
Fatigue of the floating roof - leak
F3
Failure of draining system - roof sinks
F2
Roof blockage during filling operation - roof sinks
F4
Overfill
F4
Important rain - roof sinks
F4
Dominos effects
F2
Pool/ vapours on the floating roof
P=1
Water in the tank
P=0,01
Ignition
P=0,99
No-ignition
F4
Top tank fire
g : NC1
F5
Boil-over
Thermal effects
Thermal effects
No effects

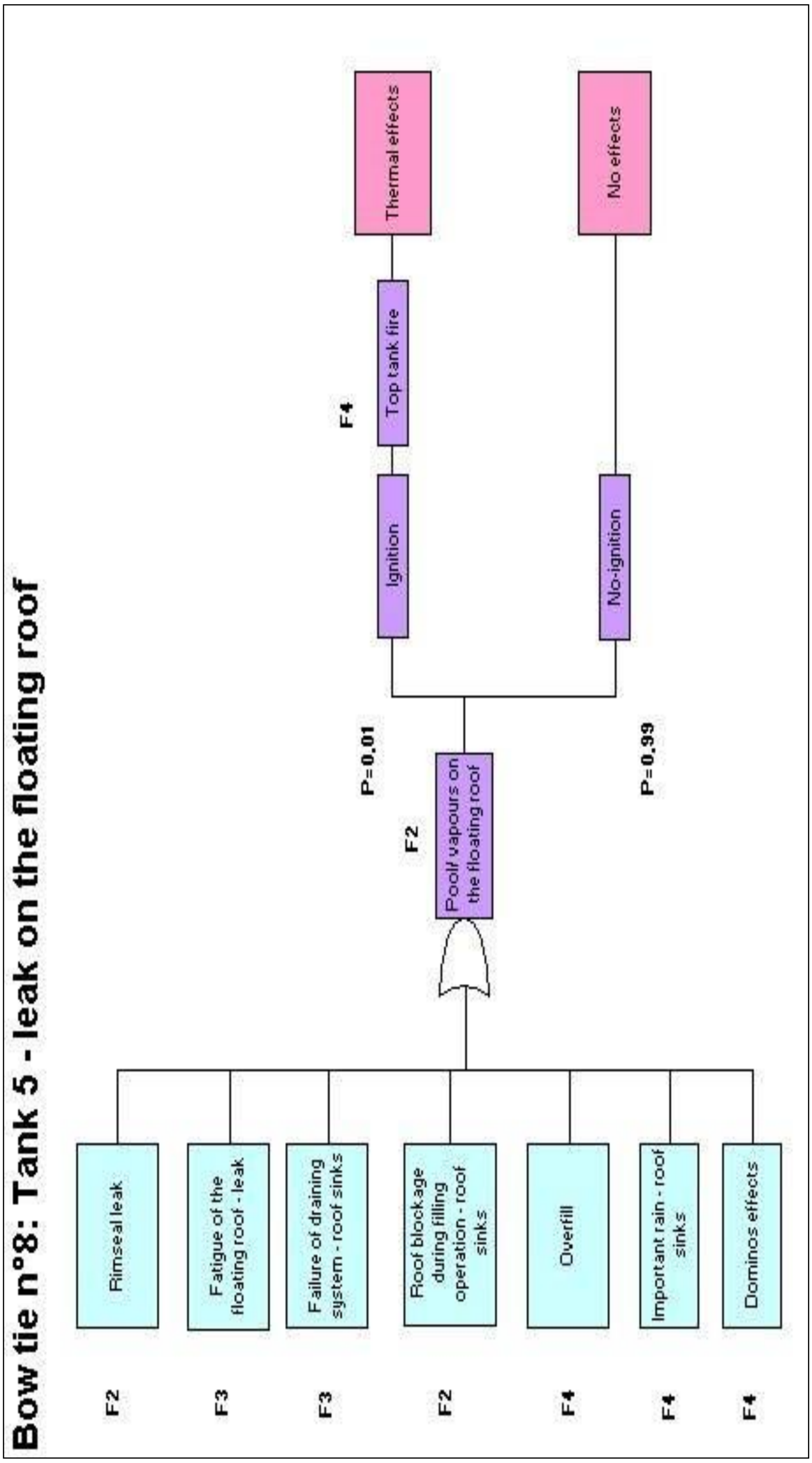

Bow-tie n°3: Tanks 2 3 4 - leak
Seal failure
F1
Draining valve left open
F3
Seal leak
a ; NC1
Error during maintenance - leak on the manhole trap
F2
b ; NC1
Error during maintenance - flange leak
F2
b ; NC1
Leak on accessories of the tank
F2
Falling object
F4
Earthquake
Flooding
Malevolence
Airplane crash
External interference
Internal corrosion
F2
c ; NC1
Erosion
F4
Tank leak
F3
Valve failure
F3
Dispatch error of incoming product
F1
d ; NC1
Wrong reception tank
Gauge failure
F2
Wrong assessment of the product volume needed
e ; NC1
f ; NC1
Overfill
F4
Dominos effects
F3
Pool in the bund and spray release
F2
P=0,01
Ignition
Pool fire
F4
Thermal effects
P=0,99
No-ignition
No effects
Pollution

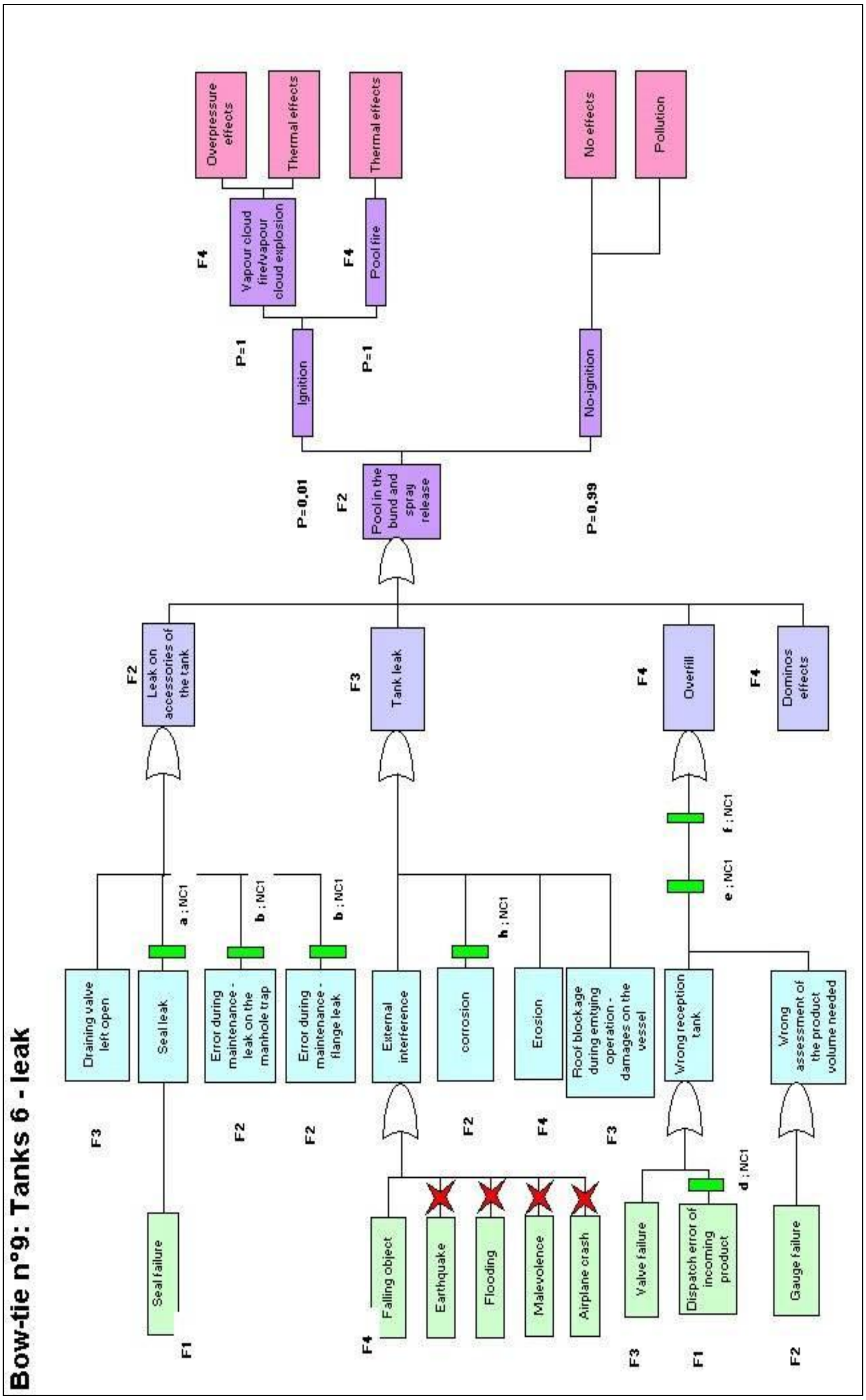

Bow-tie n°4: Tanks 2 3 4 - Tank explosion
F4
Domino effects
ATEX atmosphere in the tank and ignition
F4
Tank explosion
z ; NC2
Tank Rupture
Pool in the bund
Pool fire
Overpressure effects
Thermal effects
F6
Tank fire
Thermal effects
g ; NC1
P=1
Water in the tank
F7
Boil - over in thin layer
Thermal effects
F4
Domino effects
Fire impinging a tank
g ; NC1
F5
Tank pressurisation

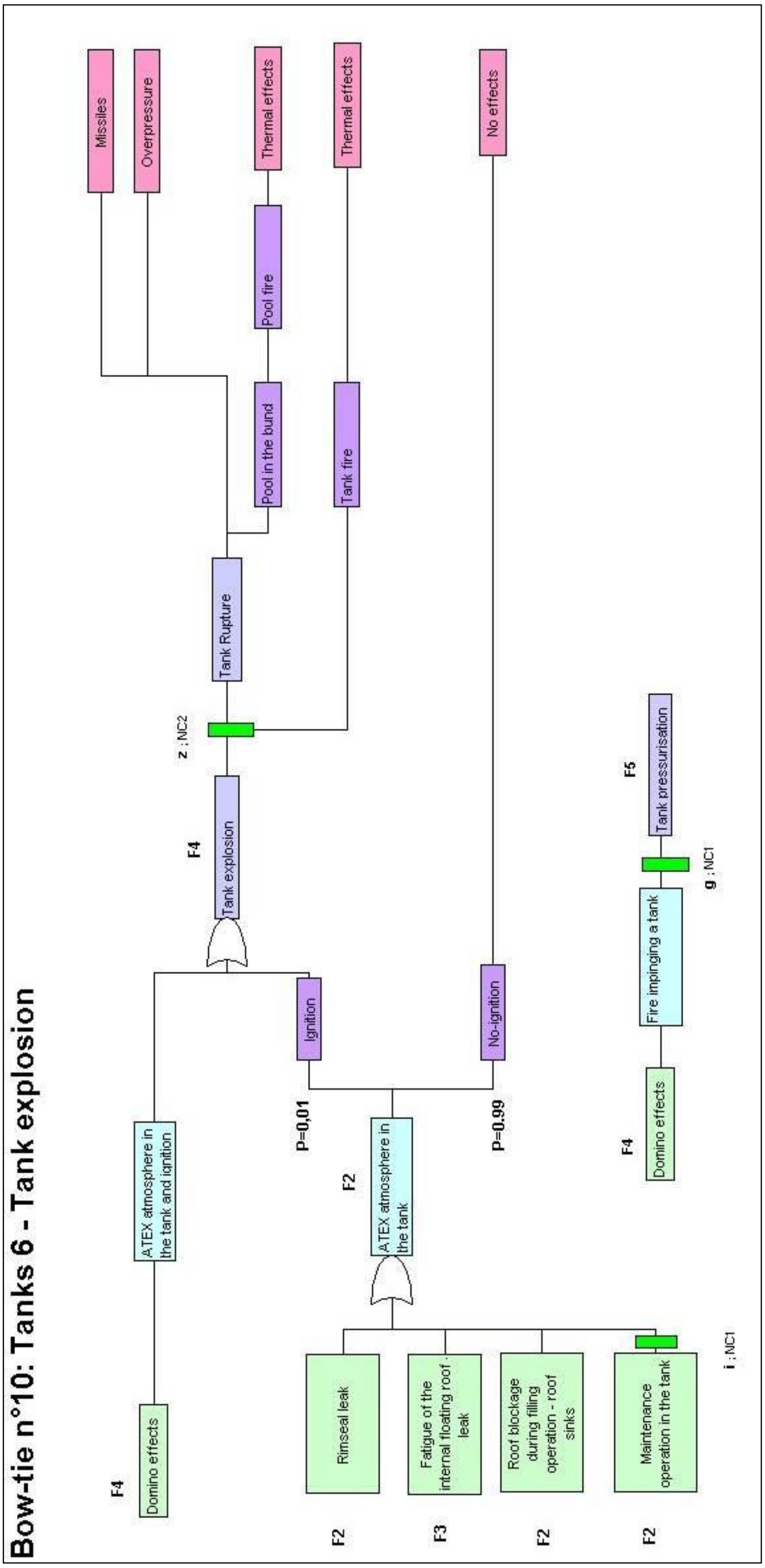

Bow-tie n°5: Tanks 7 - leak
Seal failure
F1
Seal leak
F3
Draining valve left open
a ; NC1
Error during maintenance - leak on the manhole trap
F2
b ; NC1
Error during maintenance - flange leak
F2
b ; NC1
Leak on accessories of the tank
F2
Falling object
F4
Earthquake
Flooding
Malevolence
Airplane crash
External interference
Internal corrosion
F2
c ; NC1
Erosion
F4
Tank leak
F3
Valve failure
F3
Dispatch error of incoming product
F1
d ; NC1
Wrong reception tank
Gauge failure
F2
Wrong assessment of the product volume needed
e ; NC1
f ; NC1
Overfill
F4
Dominos effects
F4
Pool in the bund and spray release
F2
P=0,001
Ignition
Pool fire
F5
Thermal effects
P=0,999
No-ignition
No effects
Pollution


Bow-tie n°6: Tanks 7 - Tank explosion
F4
Domino effects
ATEX atmosphere in the tank and ignition
F4
Tank explosion
z ; NC2
Tank Rupture
Pool in the bund
Pool fire
Thermal effects
Overpressure effects
F6
Tank fire
Thermal effects
P=1
Water in the tank
g ; NC1
F7
Boil - over in thin layer
Thermal effects
F4
Domino effects
Fire impinging a tank
g ; NC1
F5
Tank pressurisation

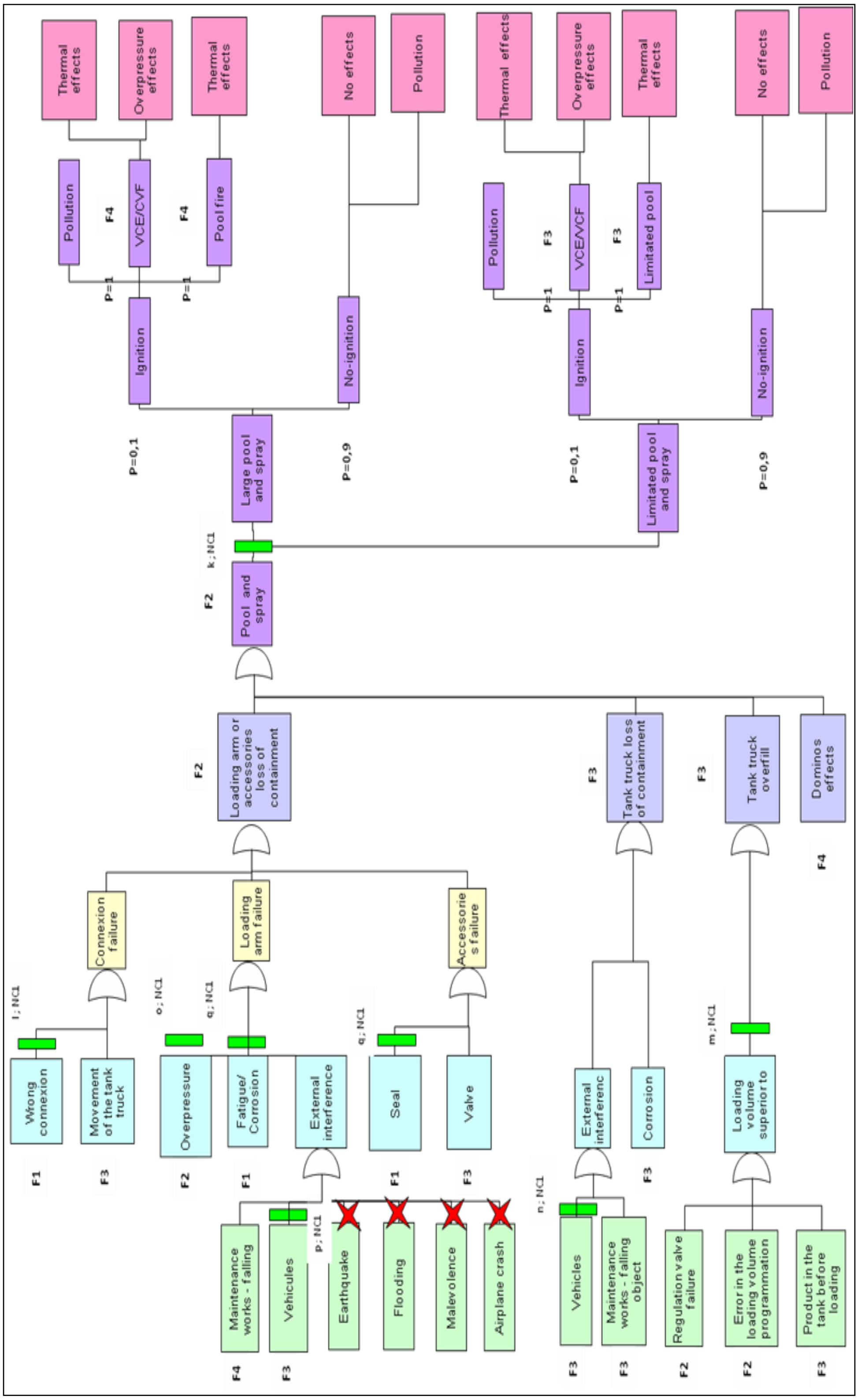

Bow-tie n°7: Tank 5 - leak
Seal failure
F1
Falling object
Earthquake
Flooding
Malevolence
Airplane crash
F4
Valve failure
F3
Dispatch error of incoming product
F1
d ; NC1
Gauge failure
F2
Draining valve left open
F2
Seal leak
a ; NC1
Error during maintenance - leak on the manhole trap
F2
b ; NC1
Error during maintenance -flange leak
F2
b ; NC1
External interference
corrosion
F2
h ; NC1
Erosion
F4
Roof blockage during emtying operation - damages on the vessel
F3
Wrong reception tank
e ; NC1
f ; NC1
Wrong assessment of the product volume needed
Leak on accessories of the tank
F2
Tank leak
F3
Overfill
F4
Dominos effects
F4
Pool in the bund and spray release
F2
P=0,01
Ignition
P=1
P=1
P=0,99
No-ignition
Vapour cloud fire/vapour cloud explosion
F4
Pool fire
F4
Overpressure effects
Thermal effects
Thermal effects
No effects
Pollution


Bow tie n°8: Tank 5 - leak on the floating roof
F2
Rimseal leak
F3
Fatigue of the floating roof - leak
F3
Failure of draining system - roof sinks
F2
Roof blockage during filling operation - roof sinks
F4
Overfill
F4
Important rain - roof sinks
F4
Dominos effects
F2
Poolf vapours on the floating roof
P=0.01
P=0.99
Ignition
No-ignition
F4
Top tank fire
Thermal effects
No effects

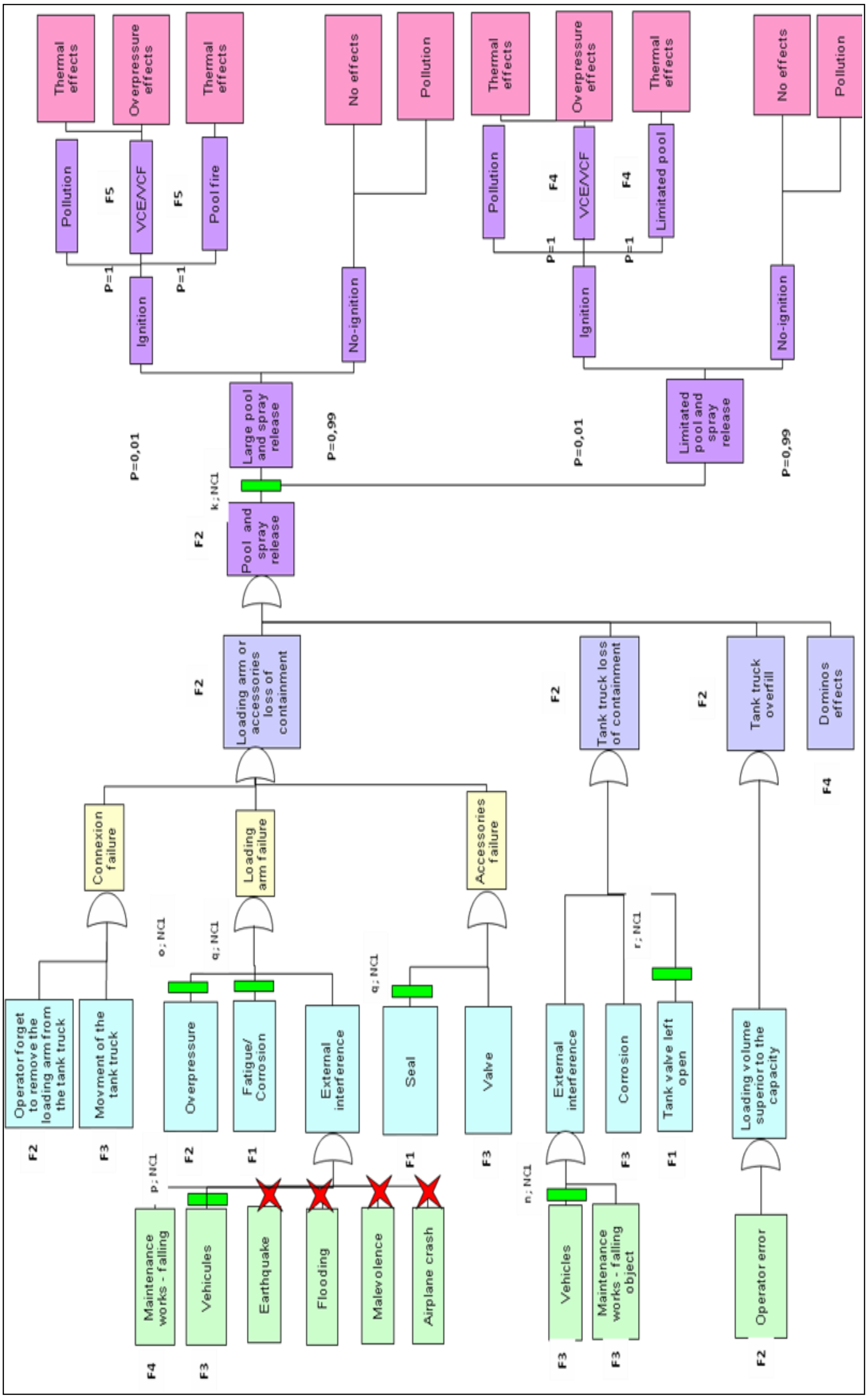

Bow-tie n°9: Tanks 6 - leak
Seal failure
F1
Draining valve left open
F3
Seal leak
a ; NC1
Error during maintenance - leak on the manhole trap
F2
b ; NC1
Error during maintenance - flange leak
F2
b ; NC1
Leak on accessories of the tank
F2
Falling object
Earthquake
Flooding
Malevolence
Airplane crash
F4
External interference
corrosion
F2
h ; NC1
Erosion
F4
Roof blockage during emtying operation - damages on the vessel
F3
Tank leak
F3
Valve failure
F3
Dispatch error of incoming product
F1
d ; NC1
Wrong reception tank
e ; NC1
f ; NC1
Gauge failure
F2
Wrong assessment of the product volume needed
Overfill
F4
Dominos effects
F4
Pool in the bund and spray release
F2
P=0,01
P=0,99
Ignition
No-ignition
P=1
P=1
Vapour cloud fire/vapour cloud explosion
F4
Pool fire
F4
Overpressure effects
Thermal effects
Thermal effects
No effects
Pollution

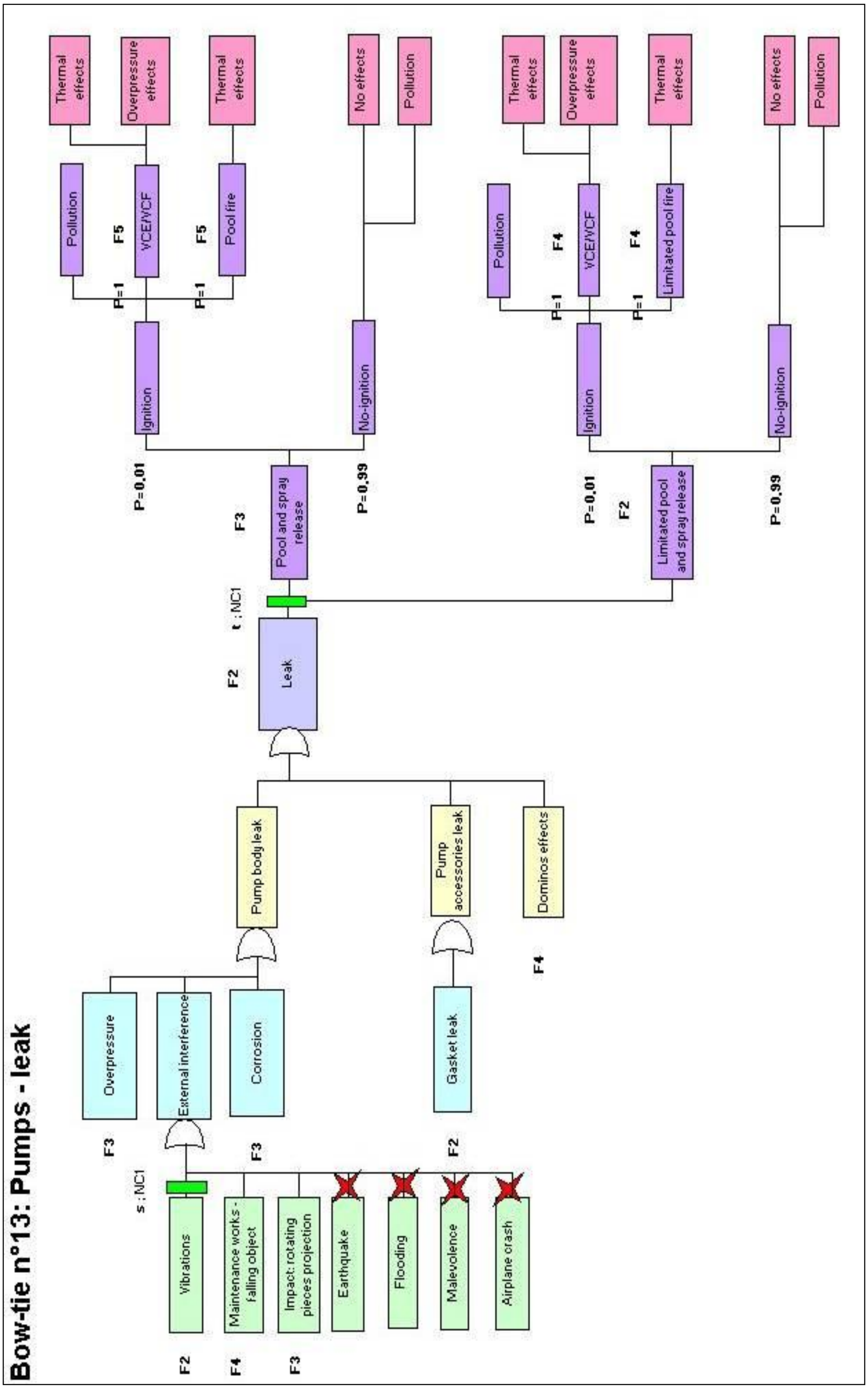

Bow-tie n°10: Tanks 6 - Tank explosion
F4
Domino effects
ATEX atmosphere in the tank and ignition
F2
Rimseal leak
F3
Fatigue of the internal floating roof - leak
F2
Roof blockage during filling operation - roof sinks
F2
Maintenance operation in the tank
i ; NC1
F2
ATEX atmosphere in the tank
P=0,01
Ignition
P=0,99
No-ignition
F4
Tank explosion
z ; NC2
Tank Rupture
Pool in the bund
Pool fire
Tank fire
Missiles
Overpressure
Thermal effects
Thermal effects
No effects
F4
Domino effects
Fire impinging a tank
g ; NC1
F5
Tank pressurisation

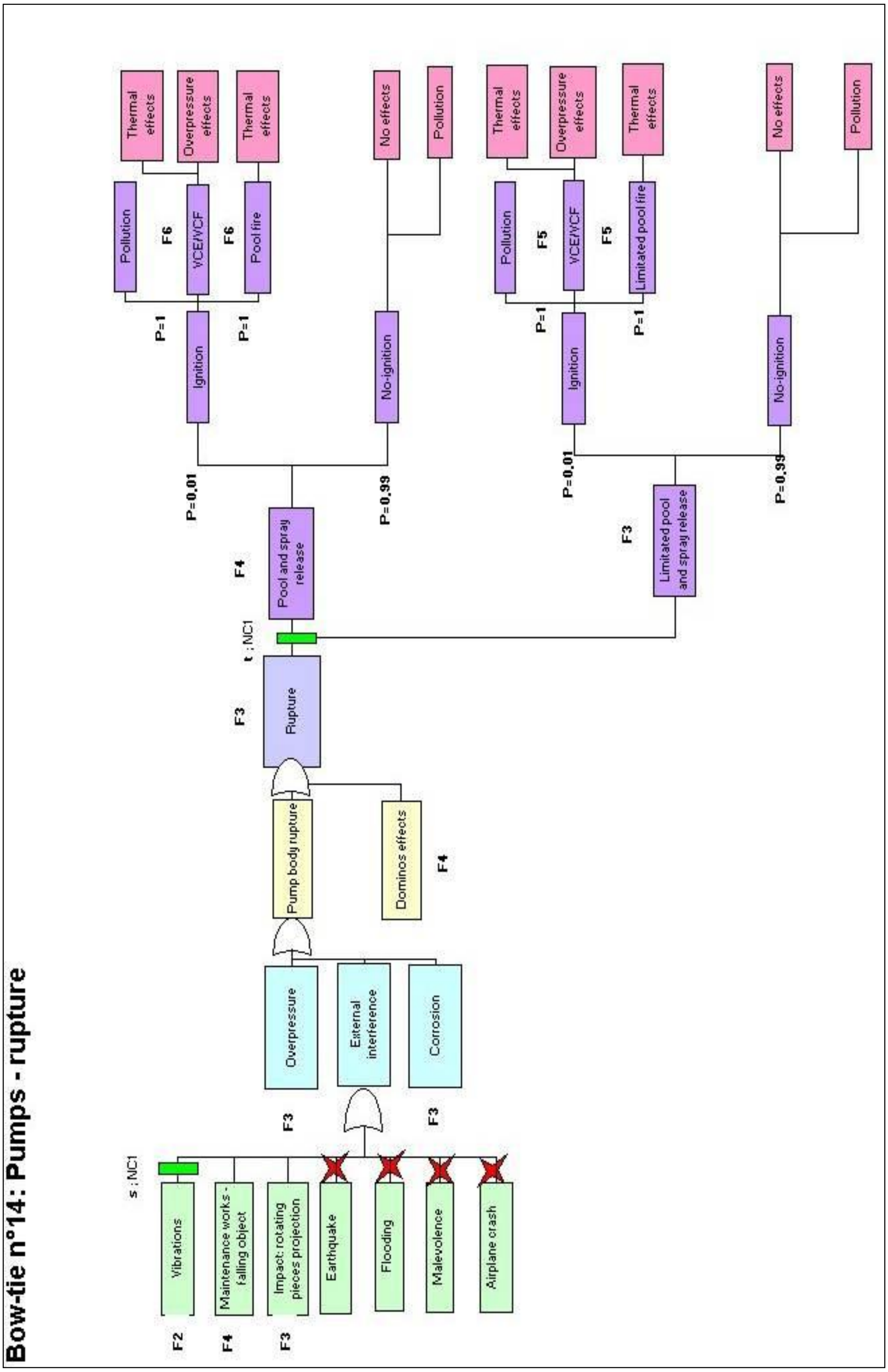
Bow-tie n°11: Loading post (loading from the bottom of the tank) - leak

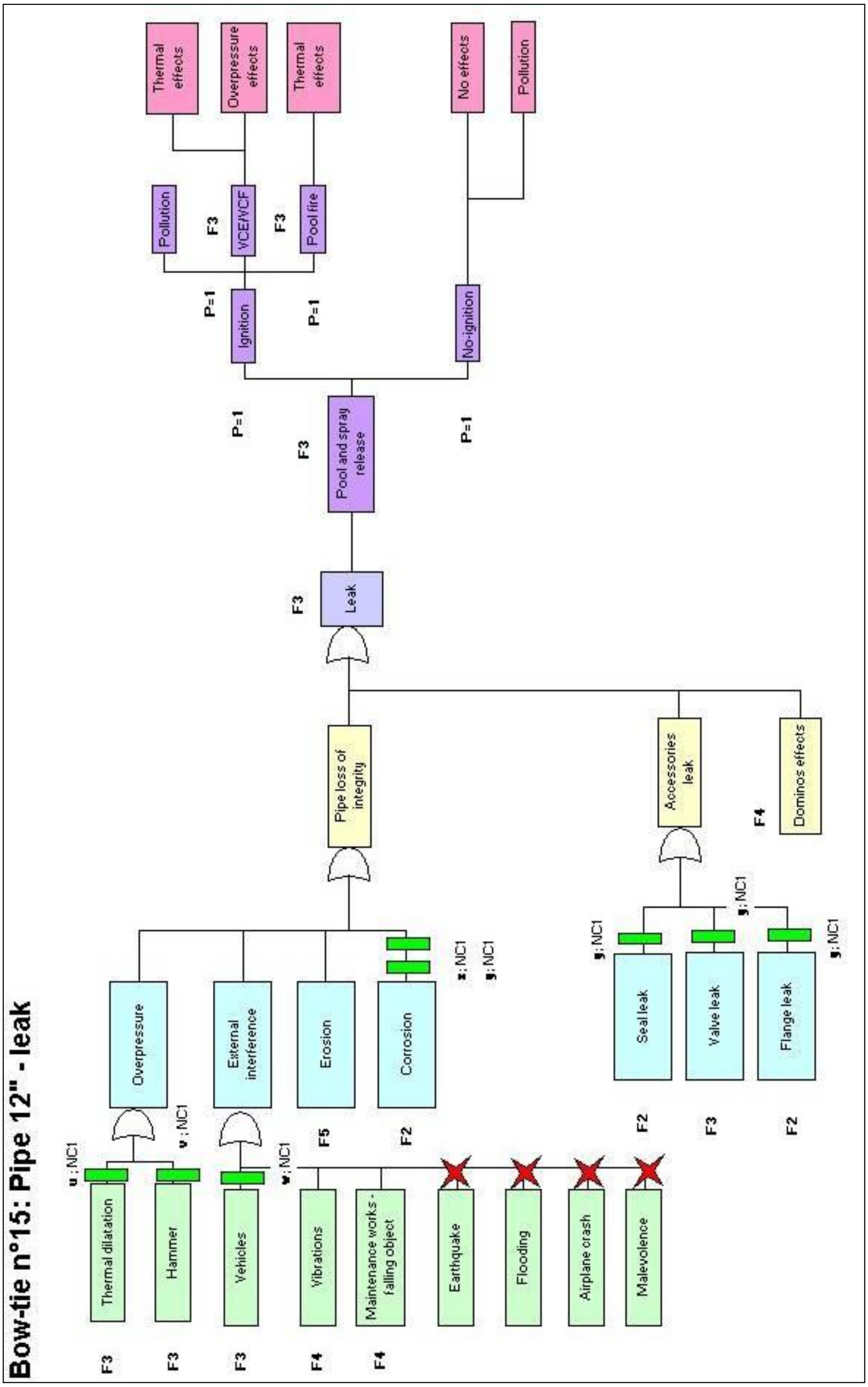


Bow-tie n°12: Loading post (loading from the top of the tank) - leak




Bow-tie n°13: Pumps - leak
Vibrations
Maintenance works - falling object
Impact: rotating pieces projection
Earthquake
Flooding
Malevolence
Airplane crash
F2
F4
F3
s ; NC1
F3
F3
F2
Overpressure
External interference
Corrosion
Gasket leak
Pump body leak
Pump accessories leak
Dominos effects
F4
Leak
F2
t ; NC1
Pool and spray release
F3
Limitated pool and spray release
F2
P=0,01
P=0,99
P=0,01
P=0,99
Ignition
No-ignition
Ignition
No-ignition
P=1
P=1
P=1
P=1
F5
F5
F4
F4
Pollution
VCE/VCF
Pool fire
Pollution
VCE/VCF
Limitated pool fire
Thermal effects
Overpressure effects
Thermal effects
No effects
Pollution
Thermal effects
Overpressure effects
Thermal effects
No effects
Pollution


Bow-tie n°14: Pumps - rupture
F2
Vibrations
s ; NC1
F4
Maintenance works - falling object
F3
Impact: rotating pieces projection
Earthquake
Flooding
Malevolence
Airplane crash
F3
Overpressure
External interference
F3
Corrosion
Pump body rupture
Dominos effects
F4
F3
Rupture
t ; NC1
F4
Pool and spray release
P=0,01
P=0,99
Ignition
No-ignition
P=1
P=1
Pollution
F6
VCE/VCF
F6
Pool fire
Thermal effects
Overpressure effects
Thermal effects
No effects
Pollution
F3
Limitated pool and spray release
P=0,01
P=0,99
Ignition
No-ignition
P=1
P=1
Pollution
F5
VCE/VCF
F5
Limitated pool fire
Thermal effects
Overpressure effects
Thermal effects
No effects
Pollution


Bow-tie n°15: Pipe 12" - leak
F3
Thermal dilatation
F3
Hammer
F3
Vehicles
F4
Vibrations
F4
Maintenance works - falling object
Earthquake
Flooding
Airplane crash
Malevolence
u : NC1
v : NC1
w : NC1
Overpressure
External interference
F5
Erosion
F2
Corrosion
x : NC1
y : NC1
Pipe loss of integrity
F2
Seal leak
F3
Valve leak
F2
Flange leak
y : NC1
y : NC1
y : NC1
Accessories leak
F4
Dominos effects
F3
Leak
F3
Pool and spray release
P=1
P=1
Ignition
No-ignition
P=1
P=1
Pollution
F3
VCE/VCF
F3
Pool fire
Thermal effects
Overpressure effects
Thermal effects
No effects
Pollution

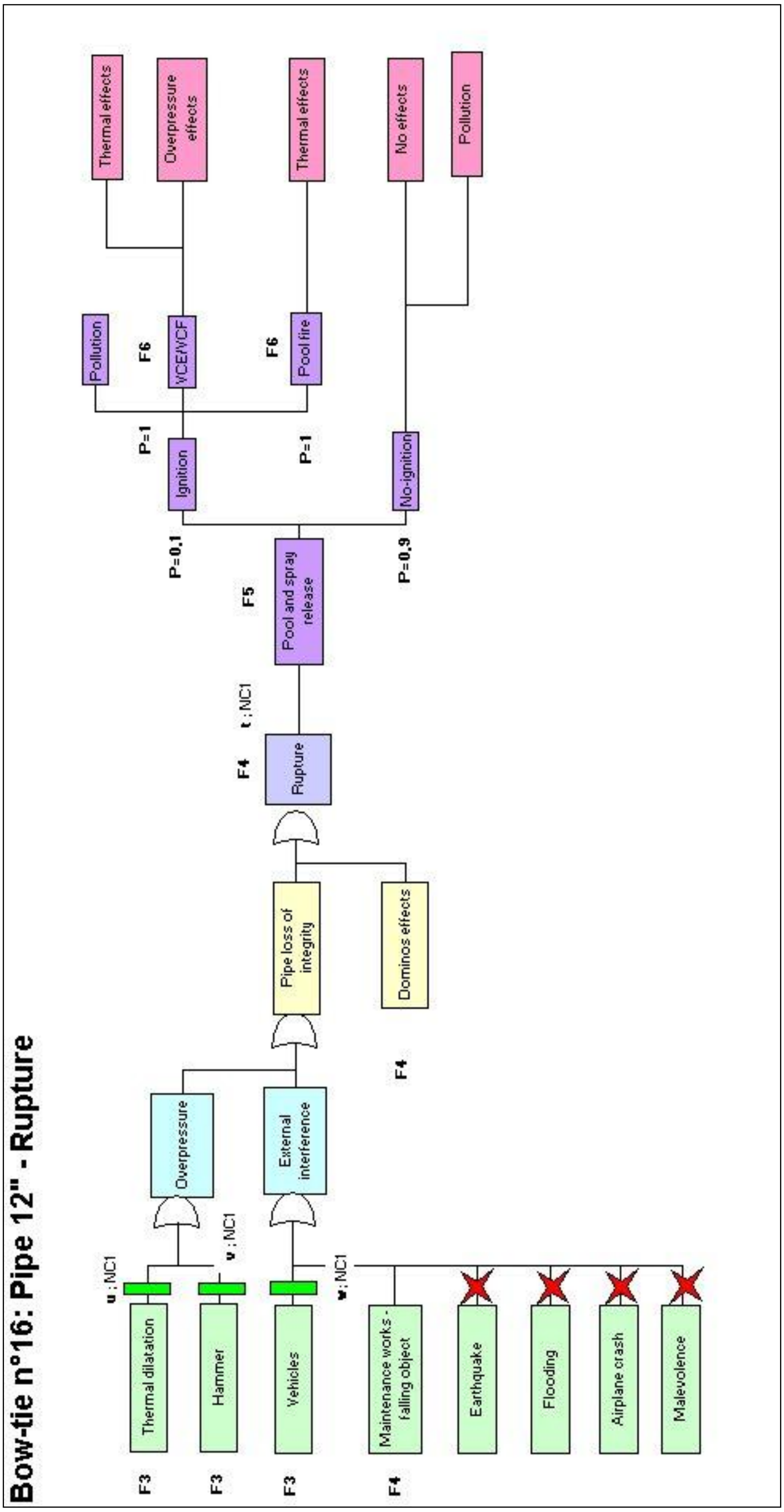

Bow-tie n°16: Pipe 12" - Rupture
F3
Thermal dilatation
F3
Hammer
F3
Vehicles
F4
Maintenance works - falling object
Earthquake
Flooding
Airplane crash
Malevolence
u ; NC1
v ; NC1
w ; NC1
Overpressure
External interference
F4
Pipe loss of integrity
Dominos effects
F4
Rupture
t ; NC1
F5
Pool and spray release
P=0,1
P=0,9
Ignition
No-ignition
P=1
P=1
Pollution
F6
VCE/VCF
F6
Pool fire
Thermal effects
Overpressure effects
Thermal effects
No effects
Pollution

Table 41 Description of barriers used by INERIS

Label	Description	Confidence level (NC)
a	Regular control and change of seals and all seals are changed after periodical tests of the tank	1
b	Complete check of the tank after maintenance	1
c	Reinforced thickness and anti-corrosion coating	1
d	Verification of the programme for the dispatch operation by two different persons	1
e	High level sensor and alarm on-site and operator instruction to stop the transfer	1
f	Very high level sensor (independent of standard level sensing) and automatic closing of the main tank valve, in-between valves and pumps	1
g	Operator detection and implementation of fire fighting equipments	1
h	Cathodic protection	1
i	Removal of vapour procedure prior to maintenance	1
k	Operators remain in loading post during loading activity and emergency stop button in place and leading to shut-down of valves and pumps and operation of Sprinkler	1
l	Loading security valve and flow regulation valve are only opened if the connection is well established (automatic detection)	1
m	High level sensor and automatic shut-down of valves	1
n	Speed bumps at the entrance of the loading post	1
o	Non-pulsating bottles	1
p	Security barrier	1
q	Weekly visual inspection	1
r	Safety cross-bar on the valve	1
s	Vibration detectors and alarm and stop procedure	1
t	Hydrocarbon detector present and automatic shut-off of the pump, valves and discontinuation of the loading operation	1
u	Pressure valves (mitigation of thermal expansion) present on the whole pipeline network	1
v	Start of distant refinery pumps is not possible when depot valves are not opened	1
w	Protection barriers along the pipeline	1
x	Cathodic protection	1
y	Visual check of the pipes and accessoires every two weeks	1
z	Frangible roof of the tank	2

Appendix 2 Domino effects

The table below presents the dangerous phenomena which have been taken into account as domino effects.

Table 42 INERIS study of domino effects

Vulnerable equipment	**Dangerous phenomena**	**Effect distance (8 kW/m² or 200 mbar)**	**Distance between equipment and dangerous phenomenon origin**	**Domino effect?**
Tank 1	Pool fire (tank 2, 3, 4)	N/A	N/A	yes
	Explosion (tank 2)	45	46	no
	Fireball after pressurisation (tank 2, 3, 4)	100	45/60/100	yes
	Vapour cloud fire (pipe leak)	N/A	N/A	yes
	Pool fire (pipe leak)	N/A	N/A	yes
Tank 2	Pool fire (tank 1, 3, 4)	N/A	N/A	yes
	Explosion (tank 3, 4)	45	30	yes
	Thin layer boil-over (tank 3, 4)	40	30	yes
	Fireball after pressurisation (tank 3, 4)	100	30	yes
	Boil-over (tank 1)	630	45	yes
	Vapour cloud fire (pipe leak)	N/A	N/A	yes
	Pool fire (pipe leak)	N/A	N/A	yes
Tank 3	Pool fire (tank 1, 2, 4)	N/A	N/A	yes
	Explosion (tank 2, 4)	45	30	yes
	Thin layer boil-over (tank 2, 4)	40	30	yes
	Fireball after pressurisation (tank 2, 4)	100	30	yes
	Boil-over (tank 1)	630	60	yes
	Vapour cloud fire (pipe leak)	N/A	N/A	yes
	Pool fire (pipe leak)	N/A	N/A	yes
Tank 4	Pool fire (tank 1, 2, 3)	N/A	N/A	yes
	Explosion (tank 2, 3)	45	30	yes
	Thin layer boil-over (tank 2, 3)	40	30	yes
	Fireball after pressurisation (tank 2, 3)	100	30	yes
	Boil-over (tank 1)	630	100	yes
	Vapour cloud fire (pipe leak)	N/A	N/A	yes

Vulnerable equipment	Dangerous phenomena	Effect distance (8 kW/m^2 or 200 mbar)	Distance between equipment and dangerous phenomenon origin	Domino effect?
Tank 4	Pool fire (pipe leak)	N/A	N/A	yes
Tank 5	Pool fire (tank 6, 7)	N/A	N/A	yes
	Explosion (tank 6)	30	25	yes
	Explosion (tank 7)	30	45	no
	Thin layer boil-over (tank 7)	20	45	no
	Fireball after pressurisation (tank 6)	30	25	yes
	Fireball after pressurisation (tank 7)	40	45	no
	Boil-over (tank 1)	630	N/A	yes
Tank 6	Pool fire (tank 5, 7)	N/A	N/A	yes
	Explosion (tank 7)	30	20	yes
	Thin layer boil-over (tank 7)	20	20	yes
	Fireball after pressurisation (tank 7)	40	20	yes
	Boil-over (tank 1)	630	N/A	yes
Tank 7	Pool fire (tank 5, 6)	N/A	N/A	yes
	Explosion (tank 6)	30	20	yes
	Fireball after pressurisation (tank 6)	30	20	yes
	Boil-over (tank 1)	630	N/A	yes
Pumps	Boil-over (tank 1)	630	N/A	yes
	Pool fire (loading area)	35	20	yes
	Vapour cloud explosion (loading area)	40	20	yes
Loading area	Boil-over (tank 1)	630	N/A	yes
	Explosion (tank truck)	N/A	N/A	yes
	Vapour cloud explosion (pump area)	45	20	yes
	Vapour cloud fire (pump area)	20	20	yes
	Pool fire (pump area)	35	20	yes

Appendix 3 Number of persons counted (French context)

Table 43 presents the number of people counted in the French regulatory context for the definition of the severity. This data is used for the risk matrix process.

Table 43 Number of persons counted in the French regulatory framework

Area studied	Number of persons counted
Public buildings with large capacity (schools, hospitals, churches, supermarket…)	Maximum capacity of the building
Shops	Between 10 and 15 pers each
Activities area (example: facility)	Maximum number of employees
Low density individual houses areas	40 pers/ha
High density individual houses areas	100 pers/ha
Buildings (below three floors)	400-600 pers/ha
Buildings (more than two floors)	600-1000 pers/ha
Roads (used by other persons than local residents) – possible regular traffic jams	300 pers/ way /km
Roads (used by other persons than local residents)	0.4 pers/km for 100 vehicles a day
Railways	0.4 pers/km for one train a day
Canals/rivers	0.1 pers/km for one barge a day
Rural areas – low frequentation (fields, forests, swamps…)	1 pers/100 ha
Rural areas - medium frequentation (gardens, vines, fishing areas…)	1 pers/10 ha
Urban open spaces (parking, public gardens, sport fields…)	10 pers/ ha

Appendix 4 Detailed aléa maps (INERIS)

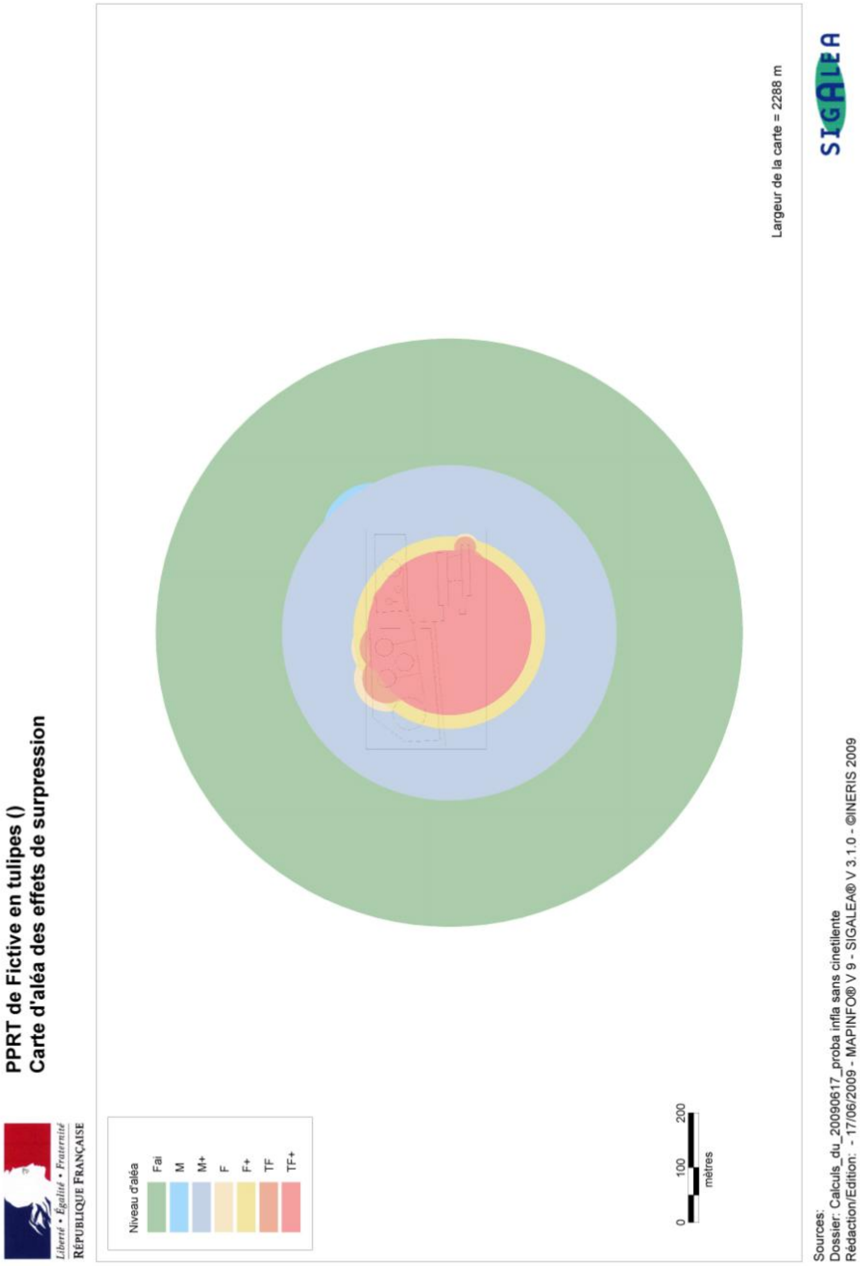


Figure 23 Overpressure aléa map

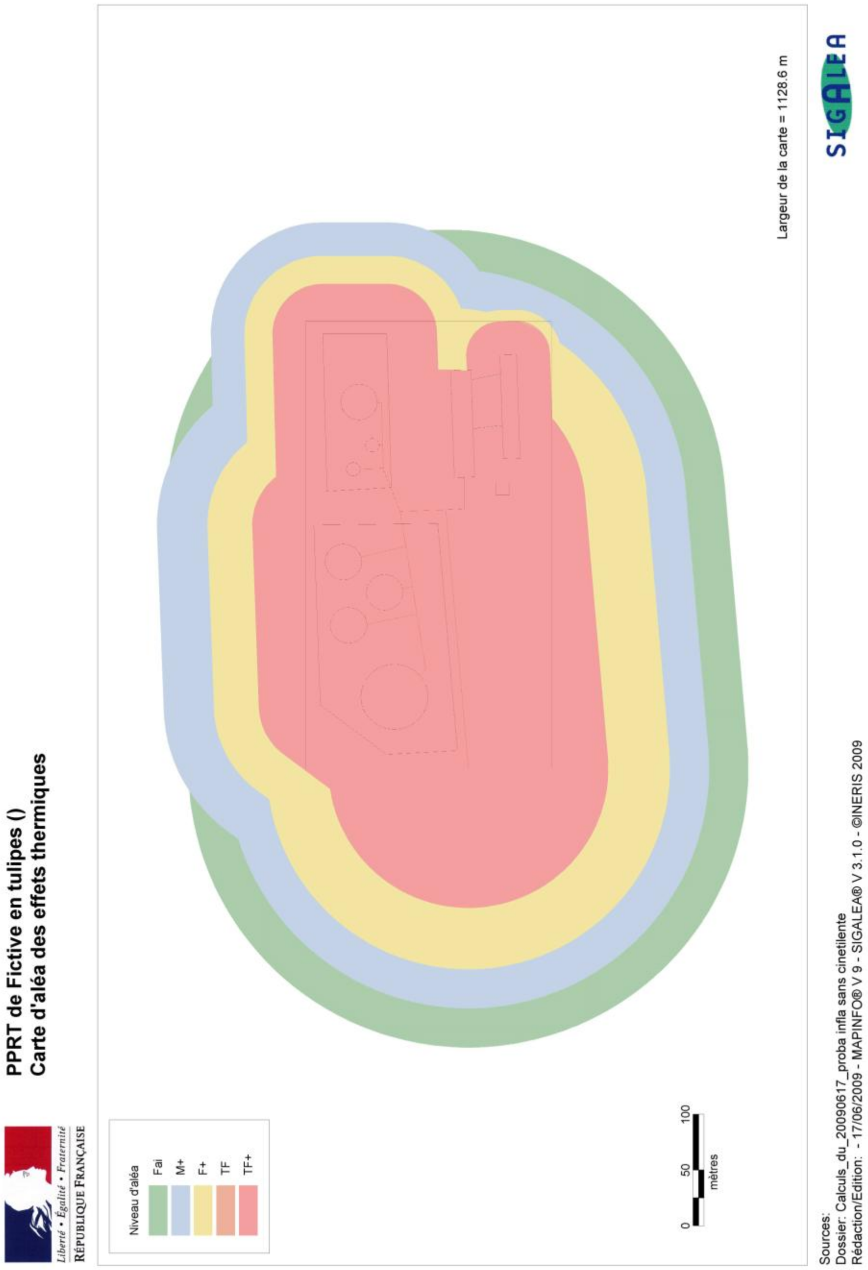


Figure 24 Thermal aléa map

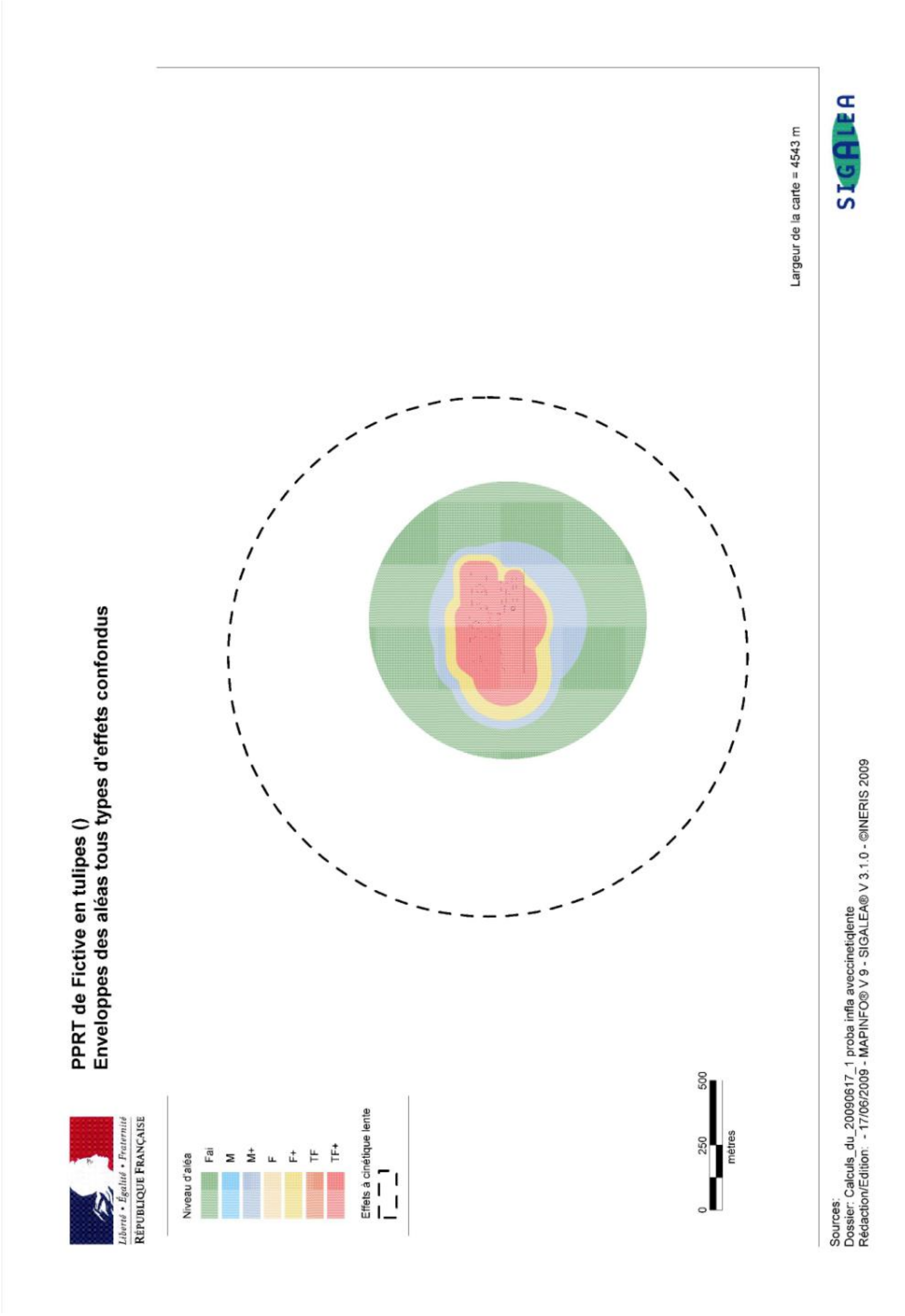


Figure 25 *Synthesis of the aléas with low kinetic dangerous phenomena*

Appendix 5 Detailed individual risk results (RIVM)

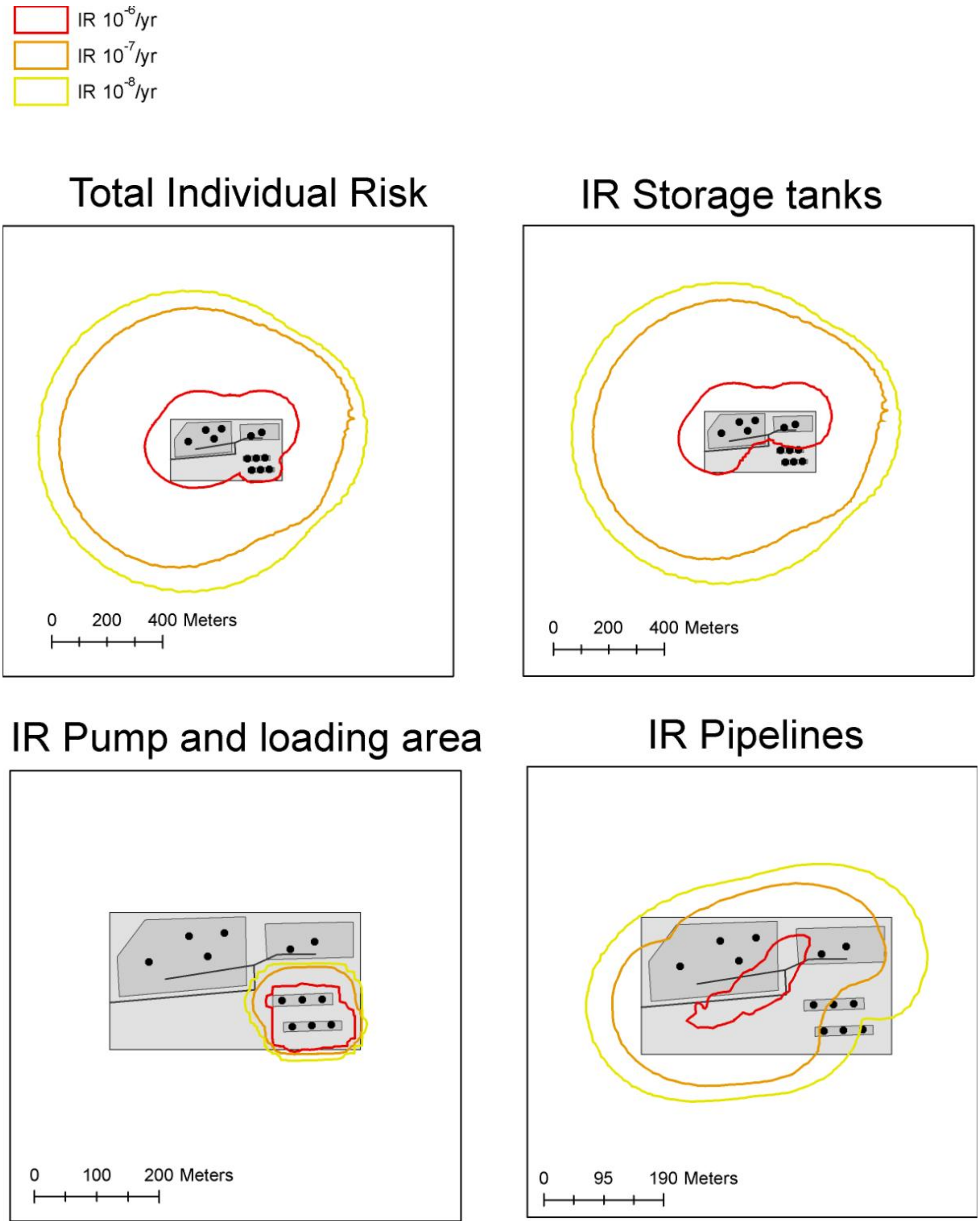


Figure 26 Individual risk contours for the entire facility, the storage area, the pump and loading area and for the pipelines (RIVM method)

Figure 27 Individual risk contours for the entire facility (RIVM method)

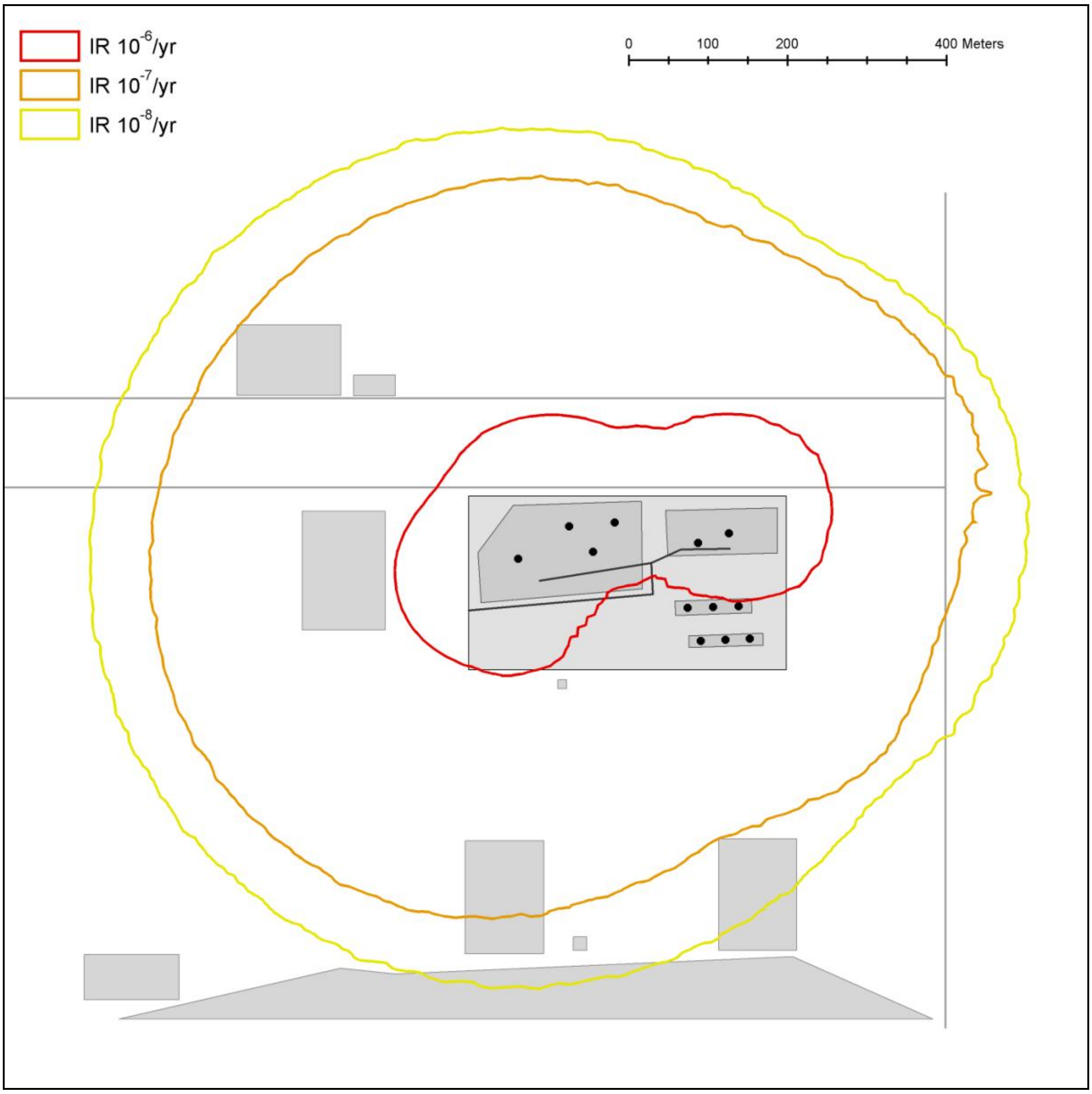


Figure 28 Individual risk contours for the storage area (RIVM method)

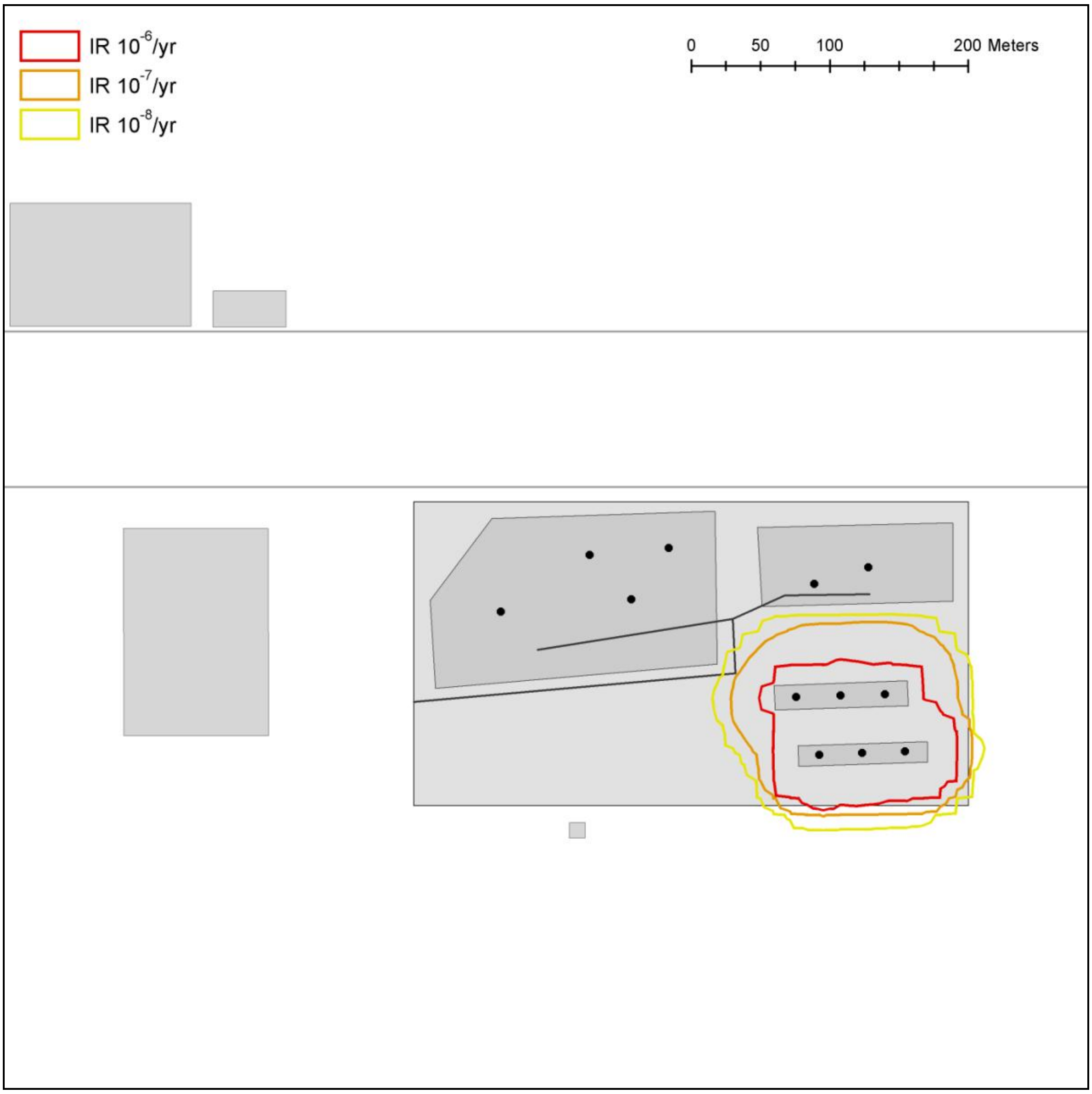


Figure 29 Individual risk contours for the pump and loading area (RIVM method)

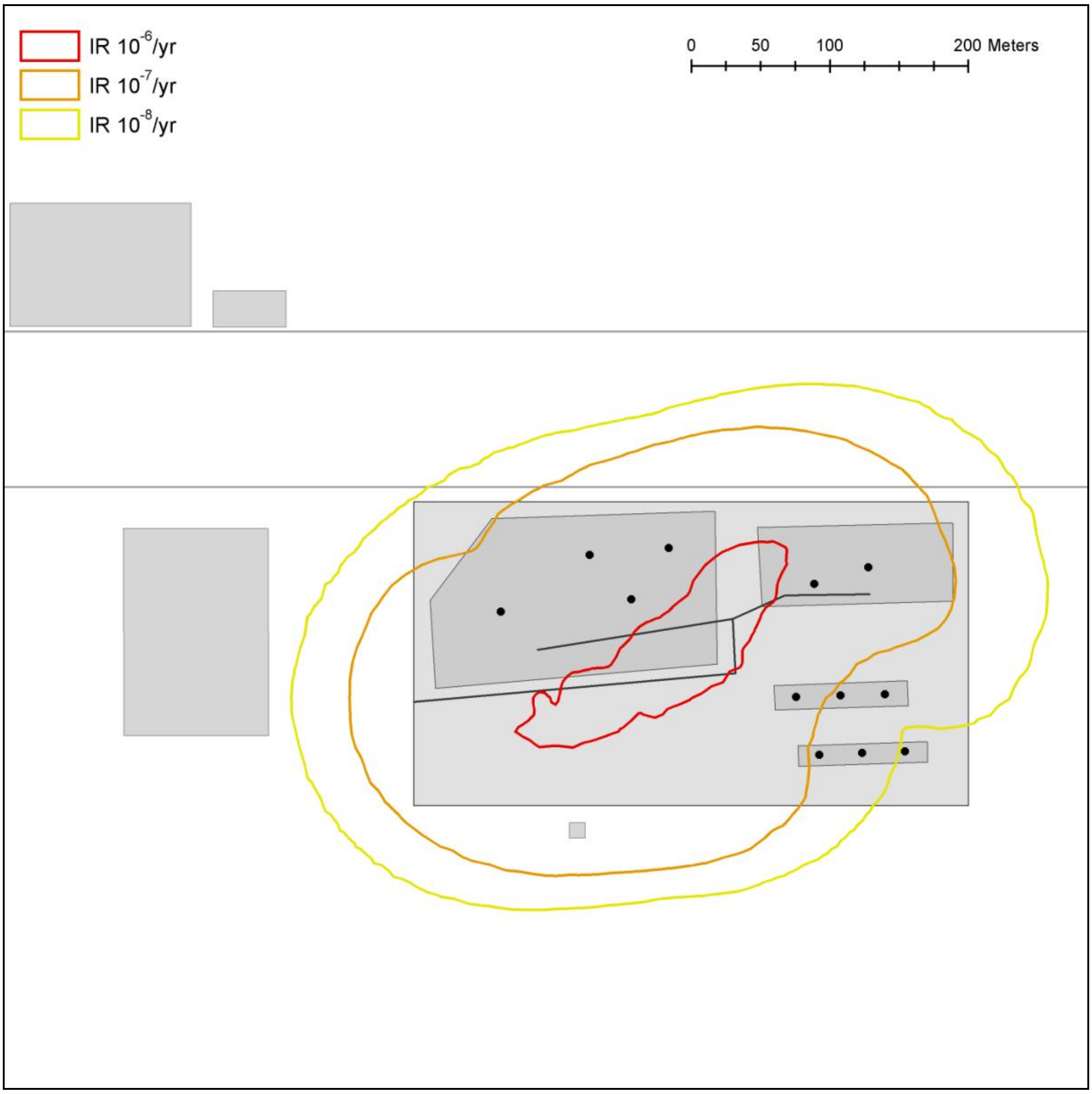


Figure 30 Individual risk contours for the pipelines (RIVM method)

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