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Land Use Planning around hazardous onshore pipelines: implementation of the French new principles

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1. Introduction

Onshore transmission pipelines are one of the common ways, in Europe as in other parts of the world, to transport large amounts of hazardous goods through great distances. They are also the safest way, according to statistics (cf *table 1*).

Table 1: Accident rate in hazardous goods transportation (France,1998-2003)

Transportation by	Road	Rail	Sea	River	Pipeline
Number of accident / 10^6 tons.year	0,7	0,41	0,19	0,13	**0,02**

Despite of this low failure rate, these pipelines may generate major accidents, as shown by the following pictures.



Jet fire on a gas pipeline (Ghislenghien, Belgium, 2004)



Leak on a crude oil pipeline (Saint-Martin-de-Crau, France, 2009)

These examples emphasize the 'major-accident hazard' potential of onshore pipelines. In most of developed countries, their operation is for that matter under safety regulation and submitted to external inspection.

But these regulation and inspections are not harmonized. As an example, in European Community, onshore pipelines are excluded from the scope of both the Seveso II Directive and the Pressure Equipment Directive, although most of them carry flammable or toxic substances at high pressure (from 10 to 80 bars).

In this context, the French national authority in charge of onshore pipelines risks-control deeply modified regulations in August 2006, for both existing and new pipelines.

In particular it was decided to deal with existing pipelines in urban or suburban areas, through new risk assessment method and land use planning principles. This paper aims at presenting and exemplifying this new framework.

2. The French pipelines network

In France, the characteristics of transmission networks are

- natural gas : 36 500 km long, 30 years old (average),
- crude oil and oil products : 9 900 km long, 44 years old (average),
- other chemical substances : 3 800 km long, 29 years old (average), miscellaneous substances (ethylene, oxygen, nitrogen, hydrogen …).

3. A new risk assessment and management method

Every existing pipeline in France shall be subject to a safety study, to be completed before the 15th of September, 2009. This study has to comply with the 2006 regulation principles: a guidance document has been developed for that purpose by the French Oil and Chemical Companies Group for Safety Studies (GESIP). The method (typical semi-quantitative risk analysis) is divided into several steps, as described in *Figure 1*.



Figure 1: Framework of pipeline safety study (source: GESIP guidance document)

Steps 1 to 4 lead to risk assessment: they are detailed in the next chapter, while risk control process is explained in chapter 5.

4. Risk assessment: a semi-quantitative analysis with harmonized criteria

4.1 Steps 1 to 3: Qualitative Analysis

Step 1: Description

Pipeline route and its environment are described in order to collect useful elements for further analysis, such as external hazards, human and natural targets in case of an accident.

Step 2: Hazard identification

Hazard identification is mainly based on past accident analyses:

- Company internal database (if experience is significant),
- National or international databases, such as
  - The European Gas pipeline Incident data Group (EGIG),
  - the oil companies' association for environment, health and safety in refining and distribution (CONCAWE).

Some severe accidents are reminded in *table 2*.

Table 2: Recent severe accidents on onshore pipelines in Europe, USA and Canada

Date and location	Short description	Damage
August 10, 1999 Liberty Hill (USA)	Flash fire and jet fire (50 meters long). Cause: third party excavation activity	1 worker missing
July 30, 2004 Ghislenghien (Belgium)	Gas leak, flash fire and jet fire (150 to 200 meters long). Cause: previous third party excavation activity (dent)	24 persons killed, 132 persons injured, buildings and cars destroyed
July 24, 2007 Vancouver (Canada)	Crude oil leak (234 m^3). Cause: third party excavation activity	Pollution in nearby houses
May 9-10, 2009 Moscow (Russia)	Flash fire and jet fire (200 meters long). Cause: overpressure in the pipeline	5 persons injured
August 7, 2009, Saint-Martin-de-Crau (France)	Crude oil leak (4000 m^3). Cause: unknown (suspicion of corrosion)	Pollution in a special area of conservation

Hazard identification can be conducted through a Preliminary Hazard Analysis (PHA) method, as shown in *table 3*.

Table 3: Extract of PHA for current route (source: GESIP guidance document)

Hazard	Initiating Event	Cause	Conse-quences	Detection measures	Risk-reducing measures
Over-pressure	Line or safety valve obstruction	Hydrate (if water)	Bridle leaks	Instrumenta-tion alarm	Drying / Hygrometric controls during maintenance activities
		Impurities	Flange leaks	Instrumenta-tion alarm	Filtration / Specification check
	Pressure after pumping too high	Regulation failure	Bridle leaks	Instrumenta-tion alarm	Pump automatic shut-down
Mecha-nical damage	Dents, scrapes, gouges	Excavator, drilling machi-ne, trencher	Leaks	Periodic surveillance	Valve emergency shut-down

Step 3: Critical events

Hazard identification (step 2) leads to the definition of critical events. Main critical events for current route are losses of containment (or leaks). GESIP guidance document defines three breach sizes:

- small (up to 12 mm diameter), mainly caused by construction or material defect, corrosion, erosion, lightning bolt ...,
- medium (up to 70 mm diameter), mainly caused by third party excavation works,
- rupture (line section), mainly caused by ground movements and third party excavation works (only for gaseous substances under pressure).

These leaks can be followed by several dangerous phenomena, to be detailed in the safety study. The main phenomena are:

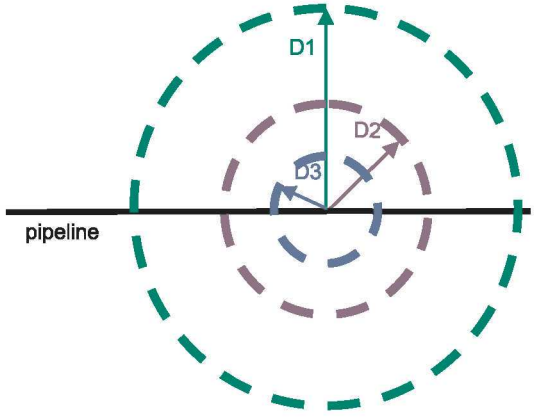
- pollution (for polluting liquids such as oil),
- cloud explosion, jet fire or pool fire in case of ignition (for flammable substances),
- toxic cloud (for toxic substances).

4.2 Step 4: Quantitative Analysis (risk level)

Qualitative analysis results are used to define the dangerous phenomena. Quantitative analysis leads to characterize each dangerous phenomenon (from each leak), on each point of pipeline route, according to three quantitative criteria: intensity, probability and gravity. In this paragraph all non-referenced data come from GESIP guidance document.

1. Intensity

Intensity is defined by three distances (in meters). Each distance is the nearest distance from the pipeline where reference effects can be observed on population, in case of fire, explosion or toxic release (cf *figure 2*).



Nota: Reference effects thresholds on human beings are defined by regulation:

- *SLE (Significantly Lethal Effects or 5% lethality) – distance D3 ;*
- *FLE (First Lethal Effects or 1% lethality) – distance D2 ;*
- *IRE (Irreversible Effects) – distance D1.*

People can be supposed to escape, after a reaction time of 3 seconds, at the average speed of 2.5 meters per second, if operator can prove lack of physical obstacle.

Figure 2: Effect distances for one phenomenon (ie jet fire after a small leak)

These distances are most often calculated by using numerical simulation models of hazardous phenomena. GESIP guidance document contains a table where generic distances for vertical jet fires from gas pipelines are given.

If a leak can cause different phenomena (fire, toxic cloud, overpressure), the worst (with the biggest effect distances) is chosen for the following analysis.

2. Gravity

For one leak (i.e. medium leak), gravity is defined in each point of the pipeline as the number of people exposed to leak effects. Population has to be counted in *effect circles*

- centered in this point (assumed to be the release point),
- with a radius equal to distances D3 (Significantly Lethal Effects or SLE), respectively D2 (First Lethal Effects or FLE). Irreversible effects (IRE) are not used here.

Some rules are given for this operation, as for examples consider an average of 2,5 person in houses, the maximal capacity in public buildings, 0,4 person per km of road and for 100 vehicles per day, 10 persons per 10^4 m² for open fields …

3. Probability

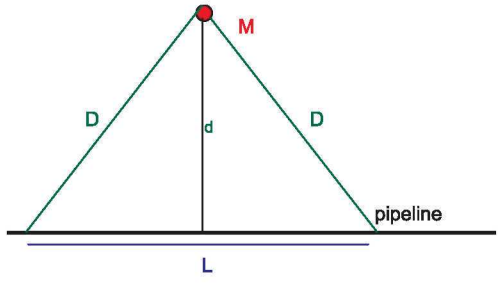
In this context probability is defined as the probability (per year) that a point M in the vicinity of the pipeline can be exposed to an intensity above a given effect level. Probability is calculated for each reference effect level (respectively SLE and FLE) and for each type of leak which can happen on any point of the pipeline, as follows:

$$P(M) = F_{leak} \times P_{ignition} \times L \times \Sigma_i(E_{CMi} \times P_{RFi}) \times C \times P_{pres} \quad (1)$$

where

$P(M)$	=	*Probability (point M)*	*[year^{-1}]*
F_{leak}	=	*Generic frequency of the given leak*	*[km^{-1}.year^{-1}]*
$P_{ignition}$	=	*Ignition probability (only for flammable substances)*	*[/]*
L	=	*Effect length*	*[m]*
i	=	*Each risk factor leading to the given leak*	
E_{CMi}	=	*Efficacy of each risk-reducing measure against the i risk factor*	*[/]*
P_{RFi}	=	*Part of the i risk factor in the given leak*	*[/]*
C	=	*Corrective factor dependant on pipeline environment*	*[/]*
P_{pres}	=	*Presence rate of people in the vicinity*	*[/]*

L is the result of geometric calculation (cf *figure 3*).



D: effect distance
(for given leak and effect)

d: distance between point M and pipeline

L: effect length ie length of the section from where the given phenomenon can reach M with an effect ≥ E

$$L = 2 \times (D^2 - d^2)^{1/2} \quad (2)$$

The length L is maximal (L_{max} = 2D) when M is on the pipeline.

Figure 3: Calculation of effect length L.

Some parameters in equation (1) are deducted from databases analyses:

- F_{leak} is observed between 1970 to 1990. It is estimated between 0.1 and 8 $(10^4.km.year)^{-1}$ for natural gas and oil pipelines,
- $P_{ignition}$ (if applicable) is estimated between 0,02 and 0,30 (dependant on substance and breach size),
- P_{RFi} : for instance 80% of natural gas pipeline ruptures are caused by third party excavation works, and 20% by ground movements.

E_{CMi} is the risk reduction factor induced by the risk-reducing measure, i.e. its PFD (Probability of Failure on Demand). C characterises the environment: as an example, suburban areas (where urbanization is growing) will more likely be submitted to excavation works than open country. E_{CMi} and C are given in GESIP guidance document (cf *tables 4* and *5*).

Table 4: Examples of recommended values for E_{CMi}

Risk factor: third party excavation works		**Risk factor: corrosion**	
Risk-reducing Measure	**E_{CMi}**	**Risk-reducing Measure**	**E_{CMi}**
Concrete sleeves + warning tape	0,01	Cathodic protection	0,01
Reinforced marking of pipeline	0,3	Internal inspection (robot)	0,01
Route surveillance (n times per month)	1 / n	Scraper	0,3
Periodic information of land owners	0,3 to 0,8	/	/

These values can be used if measures comply with GESIP recommendations.

Table 5: Recommended values for C (risk factor is third party excavation works here)

Pipeline environment	**C**	**Pipeline environment**	**C**	**Depth of cover**	**C**
Open country	0,8	Suburban or urban area	3	0,6 m	2
Car park	1	Closed and built parcel	0,05	0,8 m	1
No ground movements	1	/	/	1 m	1/3

P_{pres} is equal to 1 in first approximation, but can also be detailed (day or night, empty or full stadium ...).

4. Possible simplification of step 4

In order to simplify risk assessment:

- The pipeline can be divided in homogeneous segments, where intensity and probability are assumed to be uniform.
- Probability inside an effect circle can be assumed to be equal to the maximal one, i.e. if point M is on the pipeline and L = 2D.

Nevertheless gravity must be calculated or estimated in each point.

5. Risk control (step 5): better protecting exposed population and limit its growth

Step 5 must be conducted all along the pipeline route.

5.1 Cumulated probability

Results of previous step can be summarized as follows (cf *table 6*):

Table 6: Results of step 4

Leak	**Small**			**Medium**			**Rupture**		
Effect distances (IRE / FLE / SLE)	$D1_s$	$D2_s$	$D3_s$	$D1_m$	$D2_m$	$D3_m$	$D1_r$	$D2_r$	$D3_r$
Probability	/	$P2_s$	$P3_s$	/	$P2_m$	$P3_m$	/	$P2_r$	$P3_r$
Gravity	/	$G2_s$	$G3_s$	/	$G2_m$	$G3_m$	/	$G2_r$	$G3_r$

In *table 6*, probability to reach a point is *distributed* between the three breach sizes. Risk control process is based on "*cumulated* probability" CP, which is calculated by taking into account all leaks. Indeed, if d is the distance between pipeline and human targets:

- If $d < D2_s$: people can be simultaneously impacted by all the leaks, so
  $CP2_s = P2_s + P2_m + P2_r$ (3)
- If $d < D2_m$: people can be simultaneously impacted by medium leak and rupture, so
  $CP2_m = P2_m + P2_r$ (4)
- If $d < D2_r$: people can be impacted only by rupture, so
  $CP2_r = P2_r$ (5)

The same calculation is done for Significantly Lethal Effects (by replacing *2* with *3* in equations (3) (4) and (5).

5.2 Risk matrices

Several couples [Probability , Gravity] are then positioned in two risk matrices (cf *table 7*):

- $[CP2_s , G2_s]$, $[CP2_m , G2_m]$ and $[CP2_r , G2_r]$ are placed according to the first column gravity classes (FLE),
- $[CP3_s , G3_s]$, $[CP3_m , G3_m]$ and $[CP3_r , G3_r]$ are placed according to the second column gravity classes (SLE).

Table 7: Risk matrices (source: GESIP guidance document)

Gravity (persons)		Probability (year^{-1})					
FLE	SLE	5.10^{-7}	10^{-6}	5.10^{-6}	10^{-5}	10^{-4}	10^{-3}
>3000	>300	*	*				
1000< ≤3000	100< ≤300	*	*	*			
300< ≤1000	30< ≤100	*	*	*	*		
100< ≤300	10< ≤30						
10< ≤100	1< ≤10						
≤10	≤1						

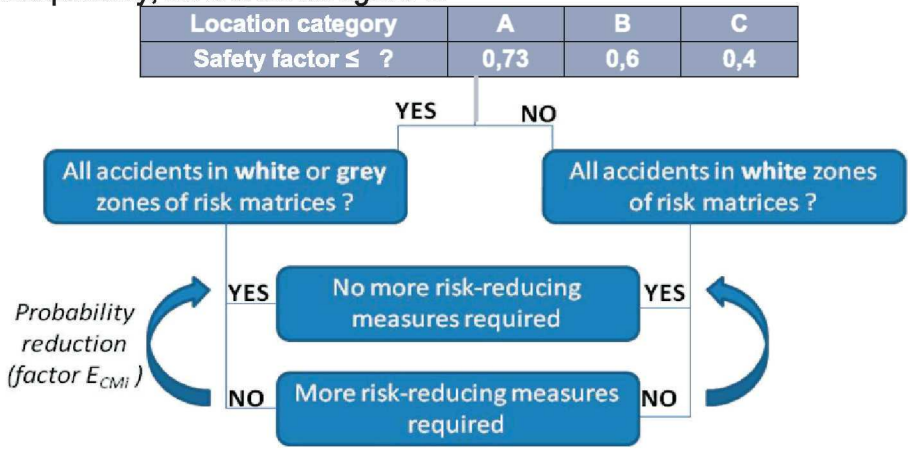
** Specific building (public buildings, very high buildings and nuclear facilities)*

5.3 Risk control process for existing exposed population

Use of risk matrices requires estimation of pipeline safety factor and location category:

- Safety factor is the ratio between internal stress due to Maximum Allowable Operating Pressure (MAOP) and elastic limit of wall material. Risk is maximal when this factor is equal to 1. The lower MAOP is, the lower this factor is and pipeline operation is safer ;
- Location categories are defined by 2006 regulation, it depends on several criteria, such as substance hazards or population density in $D3_r$ effect circle. For each location category a maximal value of the safety factor is given.

Once safety factor and location category are defined, matrices are used to assess risk acceptability, as shown on *figure 4*.



*Nota: If a **specific building** is placed in a zone with * in matrices, at least one risk-reducing measure is required.*
Public buildings are considered as far as their capacity is
- more than 100 persons for SLE,
- more than 300 persons for FLE.

Figure 4: Risk control process for existing exposed population

5.4 Limitation of exposed population growth (land use planning)

Once existing exposed population had been protected as shown on *figure 4*, operator has to follow its evolution all along the pipeline route. For that purpose a Geographic Information System is required for long pipelines, and every five years the safety study is revised.

If exposed population decreases, nothing is required.

If it increases until location category is modified, operator has to refer to the process on *figure 4* and take appropriate measures if necessary,

Construction or extension of new specific buildings (public and very high buildings, nuclear facilities) is not allowed in effect distances (SLE or FLE) of the small leak in all cases, and in effect distances of other leaks if their probability exceeds 10^{-6} per year.

5. Conclusion

Since 2006 all **existing** hazardous onshore pipelines in France have been subjected to a complete safety analysis, according to harmonized criteria. Use of risk matrices leads to an homogeneous level of risk exposure all along the pipeline route.

If population increases in the vicinity of the pipeline, operator has to take risk-reducing measures until acceptable risk level is reached.

Construction or extension of specific buildings (public buildings, very high buildings and nuclear facilities) is not allowed in effect distances of the small leak in all cases, and in effect distances of other leaks if their probability exceeds 10^{-6} per year.

New pipelines (i.e. commissioned after the 15th of September, 2006) are also subjected to the same safety analysis, with some specific requirements:

- Safety factor has to comply with location categories,
- All accidents must be positioned in white zones of risk matrices,
- Pipeline route must avoid existing specific buildings (no such buildings in effect distances of reference leak).

The method gives a harmonized framework for risk management around hazardous pipelines in France. However it does not solve all safety issues about pipelines, in particular ageing of existing networks.

6. References

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