Keeping our pipelines safe: a review of French regulations and GRTgaz methodology for natural gas pipeline safety studies.

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Although underground pipelines are recognized as very safe if not the safest means of transportation for hazardous materials, France decided in the early 2000's to reinforce the regulation. As a result, pipelines operators have to produce safety studies not only for projects but also for existing pipelines.

To realize those safety studies along its 32,000 km pipeline system, GRTgaz has developed a Geographic Information System tool, based on ESRI ArcGis® platform that enables to calculate both seriousness and probability of a pipeline failure in accordance with the risk assessment methodology proposed by the GESIP handbook.

Three failure dimensions are considered: puncture or pinhole (equivalent diameter lower or equal to 12 mm), hole (equivalent diameter between 12 mm and 70 mm) and full rupture, and ignition is considered as immediate. Effect distances are calculated with an in-house software PERSEE developed and continuously updated since 1992. PERSEE results have validated by comparison with a large number of small and large scale experiments and consequences of real accidents. Seriousness is assessed by estimating the number of people potentially affected. The probability of each scenario is estimated from GRTgaz feedback for the failure frequency and EGIG data for ignition probability.

If the risk appears to be unacceptable, additional safety measures have to be implemented by the pipeline operator in order to reduce the severity or the probability of an accident. These safety measures can be either physical (reinforced wall thickness, slabbing, etc.) or non-physical (increase in patrol frequency, landowner awareness, etc.). Their design and efficiency are defined in accordance with GESIP handbook.

Safety studies have to be updated a least once every five years in order to take into account urbanization increase in the pipelines' vicinity. On the other hand, urbanisation around pipelines is controlled by public utility easements where construction or enlargement of public facilities or high-rise buildings is submitted to a compatibility analysis that needs to be approved by the pipeline operator.

Keywords: natural gas, pipeline, safety, risk assessment

Introduction

A safe activity

Underground pipelines are considered as very safe if not the safest means of transportation for hazardous materials. In France, pipeline systems represent a total of 52,000 km (38,000 km dedicated to natural gas, 10,000 km to liquid hydrocarbons, and 4,000 km to chemicals) and the failure rate is very low. A total of 5 failures (4 pinholes and one rupture) were recorded in 2017, that means a failure rate of 0.10 per 1,000 km.yr.

Natural gas pipeline systems have also an excellent safety record as highlighted in the 10th EGIG Report (EGIG, 2018). In 2016, 17 leaks were recorded along the 142,794 km pipeline system operated by EGIG members. That corresponds to a failure rate of 0.11 per 1,000 km.yr and an average of 0.14 per 1,000 km.yr for the period 2012-2016.

GRTgaz results are in line with those figures: in 2017, 2 minor leaks were recorded along the 32,079 km GRTgaz pipeline system corresponding to a failure rate of 0.06 per 1,000 km.yr. For the period 2013-2017 the average failure rate is 0.07 per 1,000 km.yr (see Figure 1).

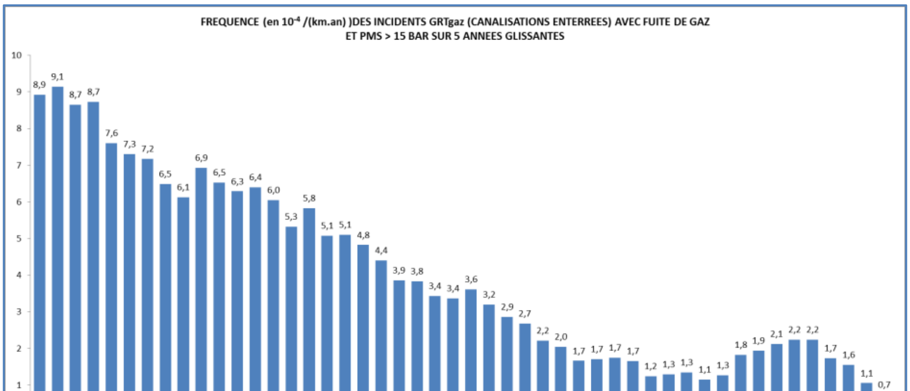

Figure 1: Five year moving GRTgaz failure frequency (per 10,000 km.yr) – period 1970 - 2017

In addition, not every high pressure gas release ignites which limits the consequences of the incidents. Since 1970, only 23 out of the 366 failures recorded on the GRTgaz pipeline system ignited, which means an ignition probability of 6.3 % in line with the EGIG 10th report (EGIG, 2018). However, it is important to note that for ruptures, the ignition probability can be higher and increases with pd^2 with p the pipeline operating pressure and d the pipeline diameter (Acton, 2016).

Potential severe consequences

Although ignited accidental natural gas releases are rare, their consequences can be severe especially in case of a rupture which is the most critical feared accident for natural gas pipelines. In the last two decades, some fatalities were caused in western Europe by pipeline ruptures (Belgium 2004, 23 casualties, Germany 2014, 3 casualties). In France, a fatal accident occurred in December 2009 as a ripper operator ruptured a pipeline (400 mm (16") nominal diameter – 67.7 bar maximum operating pressure) and was burnt to death by the ignited release (Figure 2).

Figure 2: Blénod-les-Pont-à-Mousson – December 29th, 2009

The French Regulation

Although recognizing transmission through underground pipelines as a safe activity, the French administration decided in the early 2000's to reinforce the regulation in order to ensure a higher safety for people in the vicinity of pipelines.

The regulation addresses three topics:

- reinforcement of the pipeline regulation: safety studies for projects and existing pipelines, safety management system, 10 years periodic surveillance, inspection and maintenance program,
- control of urbanisation in the vicinity of existing pipelines: new public utility easements based on effect distances, public facilities or high-rise buildings construction submitted to compatibility analysis approved by pipeline operator,
- third part interaction prevention: "one-call" online system, operator certification for works close to networks and improvement of mapping accuracy for critical networks.

Safety studies

Regulatory requirement and general methodology

Safety studies are requested for natural gas pipeline projects over 3 km since 1995 and for any project since 2003. In addition, since the Ministerial Order from the 4th of August 2006 (replaced by the current Ministerial Order from the 5th of March 2014), pipeline operators have to perform safety studies not only for projects but also for existing pipelines. Safety studies must be updated at least once every 5 years.

Safety studies are realised by the pipeline operator and submitted to the regulator either as a part of the operating permit application for pipeline project, or when updating for existing pipelines.

The safety study identifies the dangerous phenomena that might happen, analyses their causes (internal or external) and describes their probabilities and effects on people. The buildings or infrastructures located within effect distances have to be identified so that the population exposed to dangerous phenomena can be estimated. A quantitative risk analysis (severity, probability) is then performed for every dangerous phenomenon along the pipeline route. If the risk level is unacceptable, additional safety measures have to be recommended (see Figure 3).

The methodology to be followed is described in the GESIP (French professional association for safety in the oil and gas and chemical industry) handbook 2008/01 (GESIP, 2014) approved by Ministerial Order.

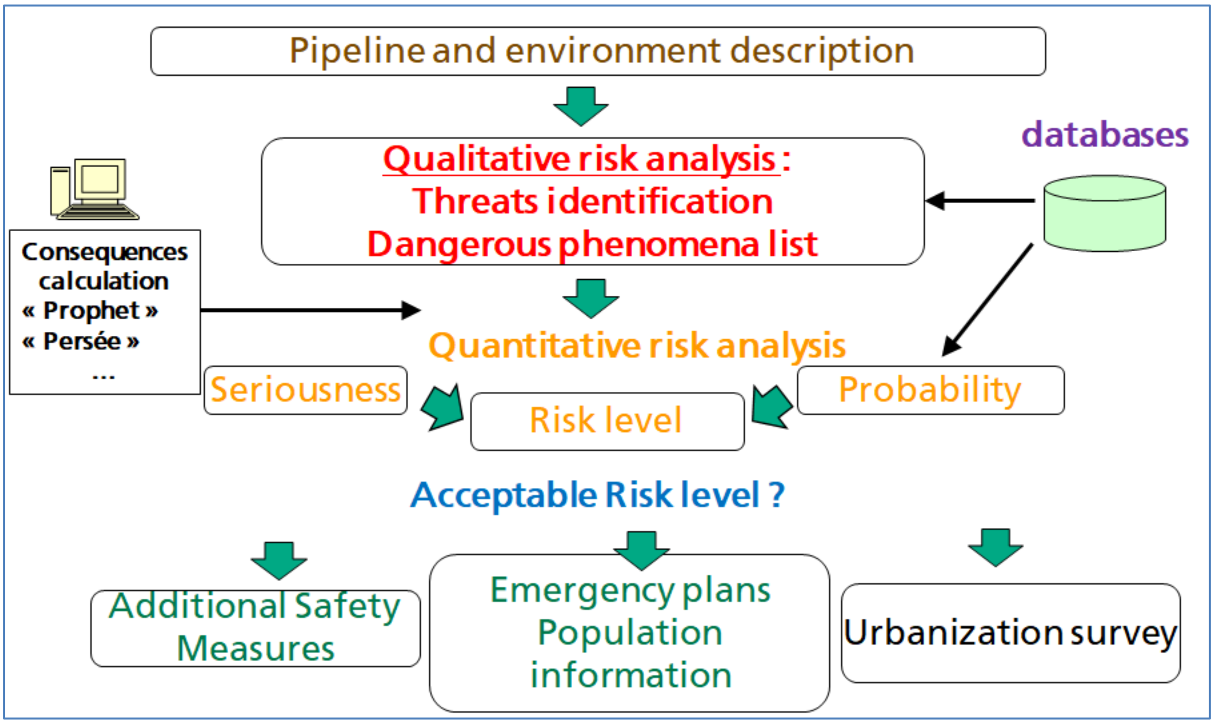

Figure 3: GESIP methodology for safety study

GRTgaz methodology

GRTgaz safety studies follow the GESIP handbook recommendations.

Three different failure dimensions are defined, based on GRTgaz feedback (see Figure 4):

- puncture or pinhole ("*petites brèches*"): equivalent diameter lower or equal to 12 mm, mainly caused by corrosion (20 %), material or construction defects (24 %) or external interferences (42 %). Pinholes and punctures represent 57 % of the total GRTgaz failures since 1970;
- hole ("*brèche moyenne*"): equivalent diameter larger than 12 mm and lower or equal to 70 mm, mainly caused by external interferences (97 %). Holes represent 26 % of the total failures recorded since 1970,
- rupture: equivalent diameter larger than 70 mm and usually larger or equal to the pipeline diameter, mainly caused by external interferences (87 %) or ground movements (10 %). Of course, rupture is the most hazardous scenario and may have severe consequences. Fortunately, ruptures occur infrequently. They represent 17 % of the total failures recorded since 1970.

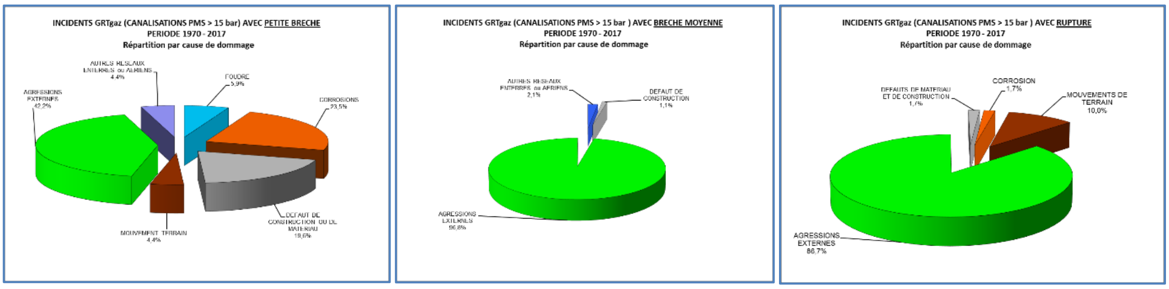

Figure 4: failure causes and dimensions

For every scenario, effect distances are calculated with PERSEE. PERSEE is an in-house software that was first developed by Gaz de France in 1992 and has been continuously upgraded by Gaz de France and GRTgaz ever since. It has been validated against a large number of tests (small or large scale including two full-scale ruptures) and real accident consequences (Osman, 2015).

For unconfined high pressure natural gas releases, the feared effect is thermal radiation produced by the ignited jet.

Due to the rapid pressure fall in the ruptured pipeline, flame size decreases rapidly in the first times of the rupture and it is the same for received thermal radiation. Moreover, exposed people are supposed to run away from the accident if they are given the possibility. Thus, effect distances are calculated considering an integrated radiation dose instead of steady thermal radiation levels. In accordance to the Ministerial Order from the 29th of September 2005, three different distances, corresponding to different risks, are calculated:

- IRE : injury threshold, corresponding to a thermal dose of 600 $[(kW/m^2)^{4/3}].s$
- PEL : lethality threshold, corresponding to a thermal dose of 1,000 $[(kW/m^2)^{4/3}].s$
- ELS : significant lethal effects, corresponding to a thermal dose of 1,800 $[(kW/m^2)^{4/3}].s$

Some distances, corresponding to usual (nominal diameter, maximum operating pressure) configurations, are given in the GESIP hand book. Other configurations have to be calculated with PERSEE.

Seriousness assessment

Depending on the pipeline diameter and pressure, effect strips are then defined along the pipeline route within which the global population has to be estimated in order to assess the severity of every scenario.

This is achieved by using the IGN ("*Institut Géographique National*") BDTopo® which identifies every geographical data of the French territory. Specific elements like buildings, roads, railways, etc., that are identified in the effect strips are recorded in the GRTgaz environmental database and are enriched with specific data such as population, traffic, etc., that are collected by contractors.

A specific focus is made on public facilities (schools, hospitals, commercial or recreation centres, etc.) with a capacity over 100 people. In accordance with the Ministerial Order from the 4th of March 2014, such facilities are to be avoided in the rupture ELS strip or request at least that some specific safety measures should be taken to reduce the rupture probability to an acceptable level. The same focus is made for high rise buildings, nuclear plants or public facilities over 300 visitors in the PEL strip.

Figure 5 shows an example of the severity calculation process.

Figure 5: Seriousness calculation

The pipeline nominal diameter is 500 mm (20") and the maximum operating pressure is 25 bar. Effects distances for IRE (green line), PEL (orange) and ELS (purple) are respectively 145 m, 110 m and 75 m. The pipeline is settled in a highly urbanised area (Paris suburb). In addition, a nursery and a functional re-education centre have been identified in the ELS strip as well as busy transport infrastructures: RD 7 (45,000 vehicle/day), RD 911 (37,000 vehicle/day) and aerial metro line (570 train/day).

As a result, the maximum exposed number of people are 950 in the ELS band and 1,500 in the PEL band, respectively.

Probability assessment

In accordance with the GESIP 2008/01 handbook recommendations (GESIP, 2014), the probability (per yr) is calculated for every scenario and every effect distance with the following formula:

$$P = F_{(failure/(km.an))} \text{ x } Prob_{(inflammation)} \text{ x } L_{(effect)} \text{ x}(\Sigma(E_{MCi} \text{ x } P_{(risk\ factor)i} \text{ x } C_i)) \text{ x } P_{(presence)}$$

where

- F is the generic frequency (per 1,000 km.yr) of the scenario. This frequency is defined as the average frequency on the period 1970 – 1990. When looking at Figure 1, it is easy to figure out that historical frequency is higher than current failure frequency. This has been done on purpose, to ensure that the frequency remains conservative despite improvements in pipeline construction and operation that have occurred since 1990.

- $Prob_{(inflammation)}$ is the ignition probability of the scenario. It is derived from EGIG data (EGIG, 2013).
- $L_{(effect)}$ (km) is the length of pipeline section that could potentially expose a person to the feared effect (ELS, PEL). It is commonly considered as equal to twice the effect distance, assuming that within the effect strip, the initial distance between the pipeline and the exposed person is not taken into consideration.
- E_{MCi} is the efficiency (]0, 1]) of safety measures taken to mitigate risk factor "i" that creates the effect distance. The lower the E_{MC}, the more efficient the measure (or the combination of measures) is.
- $P_{(risk\ factor)I}$ is the share (]0, 1]) taken by risk factor "i" in the failure that creates the effect distance. It is derived from GRTgaz feedback (see figure 4). As an example, third part interactions cause 87 % of ruptures.
- C_i is an adjustment factor usually equal to 1 except for third part interactions. In that particular case, it is derived from a calculation taking into account the type of area (rural, semi-urban, urban) and the pipeline depth (GESIP, 2014).
- $P_{(presence)}$ is the occupancy rate. Usually set to 1 it can be used when looking at very specific events with a large audience but occurring rarely (e.g. music festival).

Figure 6 shows an example of probability calculation for the same pipeline section as Figure 5.

Figure 6: Probability calculation

For a 500 mm nominal diameter pipeline the generic rupture frequency is 0.107 per 1,000 km.yr and the ignition probability is 33 %. The pipeline is buried at a minimal depth of 0.8 m in an urban area. Some sections are already protected with PE slabs or steel plates.

Depending on the presence of pipeline protection, the resulting probability for each effect distance is:

- ELS: 1.3 10^{-5} per yr for unprotected sections (brown) and 1.3 10^{-7} per yr for protected ones (light brown),
- PEL: 1.9 10^{-5} per yr for unprotected sections and 1.3 10^{-7} per yr for protected ones.

Risk analysis

Once both seriousness and probability have been calculated for every scenario along the pipeline route, the risk analysis is performed both for ELS and PEL, using GESIP matrices (see Figure 7).

Matrice de risque pour la zone des effets létaux significatifs – ELS							
Nexp(ELS)	**P_{point} (ELS)≤5.10^{-7}**	**5.10^{-7}<P_{point} (ELS)≤10^{-6}**	**10^{-6}<P_{point} (ELS)≤5.10^{-6}**	**5.10^{-6}<P_{point} (ELS)≤10^{-5}**	**10^{-5}<P_{point} (ELS)≤10^{-4}**	**10^{-4}<P_{point} (ELS)≤10^{-3}**	**10^{-3}<P_{point} (ELS)**
N>300	*	*					
100<N≤300	*	*	*				
30<N≤100							
10<N≤30							
1<N≤10							
N≤1							
Matrice de risque pour la zone des premiers effets létaux– PEL							
Nexp(PEL)	**P_{point} (PEL)≤5.10^{-7}**	**5.10^{-7}<P_{point} (PEL)≤10^{-6}**	**10^{-6}<P_{point} (PEL)≤5.10^{-6}**	**5.10^{-6}<P_{point} (PEL)≤10^{-5}**	**10^{-5}<P_{point} (PEL)≤10^{-4}**	**10^{-4}<P_{point} (PEL)≤10^{-3}**	**10^{-3}<P_{point} (PEL)**
N>3000	*	*					
1000<N≤3000	*	*	*				
300<N≤1000	*	*	*	*			
100<N≤300							
10<N≤100							
N≤10							

Figure 7: GESIP risk matrices

For recent pipelines, grey or black boxes are unacceptable and additional safety measures have to be taken in order to return to a white box.

For pipelines commissioned before August 2006, a grey box is acceptable.

In case of a starred box, a specific analysis is requested if there are public facilities, high-rise building or nuclear plant in the effect distances (a * grey box is then considered as black and a * white box as grey).

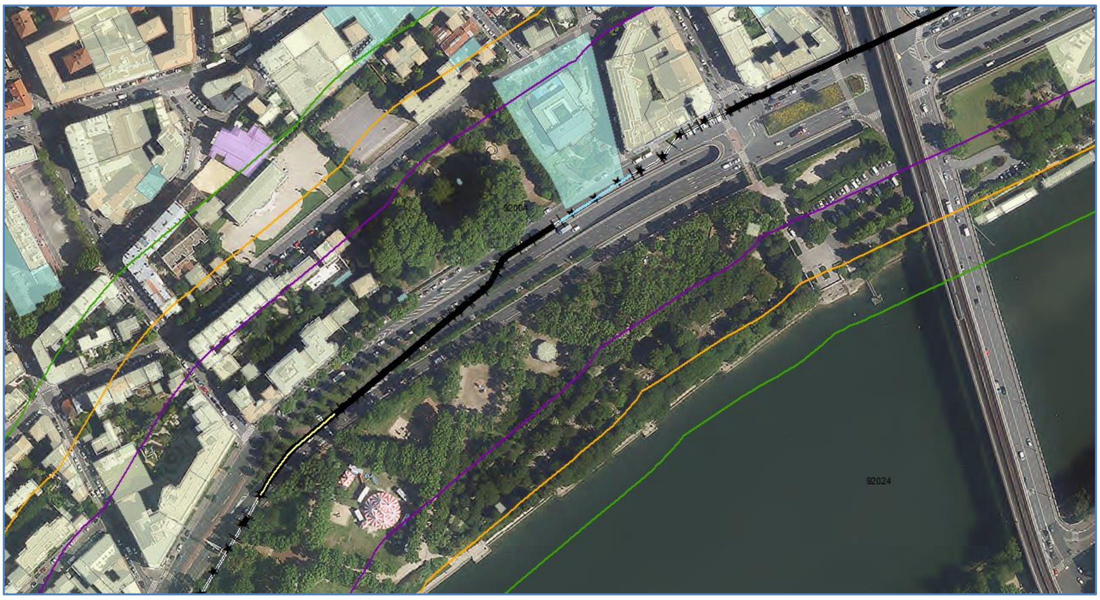

Figure 8: Risk calculation

Figure 8 shows results for the pipeline section already used for seriousness and probability calculations. Two sections highlighted in blue and yellow have been chosen to illustrate the analysis performed with the software.

Section	Number of exposed people		Probability (per yr)		Box colour		Acceptable
	ELS	PEL	ELS	PEL	ELS	PEL	
Blue	940	1,460	1.3 10^{-7}	1.9 10^{-7}	White *	White *	Yes
Yellow	490	950	1.3 10^{-5}	1.9 10^{-5}	Black	Black	No

Table 1: risk analysis for two sections

The blue section is already protected by steel plates and the resulting risk level is acceptable although a public facility (nursery) is present in the ELS strip. On the other hand, yellow section risk level appears as unacceptable and additional safety measures have to be taken to return into grey boxes for both effect distances.

Additional safety measures

When the risk level appears to be unacceptable according to GESIP criteria, additional safety measures have to be taken to reduce either consequences or (more frequently) probability of failure.

As shown on Figure 4, external interference is a very important cause of failure especially for ruptures or holes. As a consequence, most of the safety measures are designed to protect pipelines from this failure cause.

They can be either physical (e.g. reinforced wall thickness, slabs) or non-physical measures (e.g. survey frequency increase, landowner awareness). Some measures can also be combined with each other to improve their efficiency (e.g. survey frequency increase and larger number of marker posts).

Figure 9: Example of physical protection – PE slabs

Approved measures and their efficiency (probability reduction factor) are given in GESIP 2008/01 handbook. Their design and implementation are described in GESIP 2008/02 handbook.

When needed, the software suggests the minimal measure (or combination of measures) to reach an acceptable risk level. For example, on the pipeline section presented on Figure 9, the different suggested safety measures are: larger number of marker posts and landowner awareness (purple line), larger number of marker posts and increased patrol frequency (light blue line) and physical protection (dark blue line).

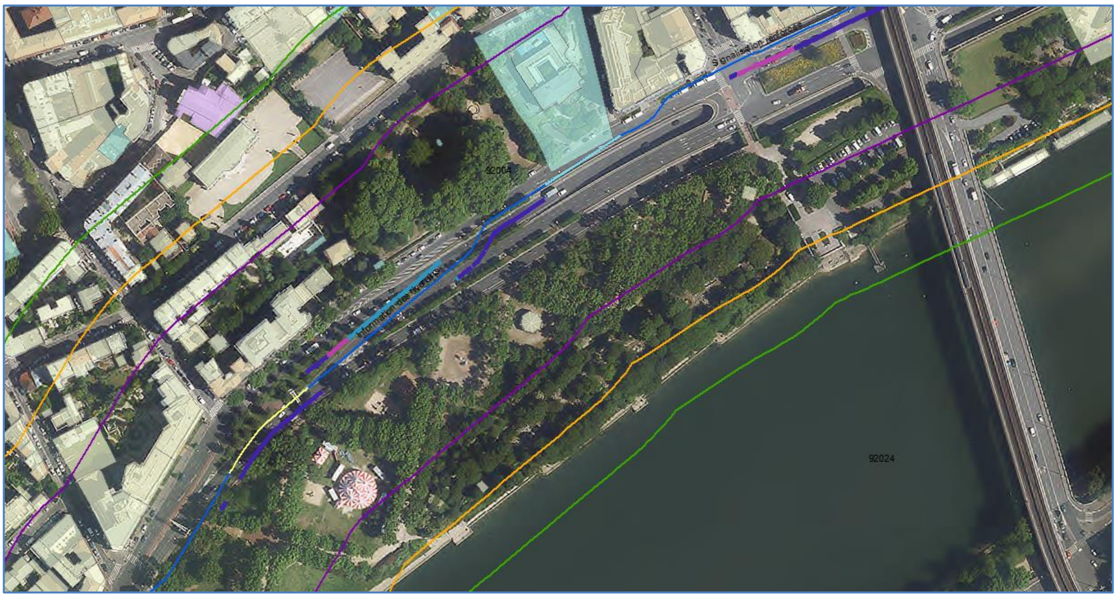

Figure 9: Additional safety measures

In accordance with the Ministerial Order from the 5th of March 2014, non-physical measures are implemented in the inspection and maintenance program within one year after the safety study approval, whereas physical measures must be implemented within three years.

Urbanisation survey

Since 2012, public easements have been defined around pipelines that are based on effect distances:

- SUP1: based on rupture PEL,
- SUP2: based on pinhole PEL,
- SUP3: based on pinhole ELS.

Those public easements are registered in local urban planning documents and are linked with urbanisation restrictions:

- construction or enlargement of public facilities with a capacity over 300 people or high-rise buildings is forbidden within the SUP3 band,
- construction or enlargement of public facilities with a capacity over 100 people or high-rise buildings is forbidden within the SUP2 band,
- construction or enlargement of public facilities with a capacity over 100 people or high-rise buildings within the SUP2 band is submitted to a risk based compatibility analysis approved by the pipeline operator or, in case of a disagreement, the regulator.

The compatibility analysis is realised by the project owner and uses data from the pipeline current safety study. If the project leads to an unacceptable risk level, additional physical safety measures may be proposed by the pipeline operator and the resulting fees are then supported by the project owner.

Any other construction project is allowed without restriction within the SUP bands (apart from the pipeline construction and operation right of way respect). Nevertheless, the pipeline operator has to be informed of any construction demand within the SUP1 band and it is his responsibility to take into account urbanisation increase when updating the safety study (at least once every five years).

Conclusion

In order to fulfil regulatory obligations, GRTgaz has developed a comprehensive tool that enables to calculate the risk level along pipelines route and, when needed, to propose additional safety measures to reach an acceptable risk level according to French regulation criteria.

In addition, GRTgaz has developed its own environmental geographical database. This database is continuously updated either by comparison with IGN BDTopo® regular updates or with information received from construction project owners or local authorities.

Thus, GRTgaz takes as many actions as reasonably possible to ensure that its pipeline system protection and maintenance are in line with the urbanisation and that the risk level remains acceptable according to French regulation and standards criteria.

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