Control of major accident hazards involving land transmission pipelines

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Land transmission pipelines are one of the common ways, in Europe as in other parts of the world, to carry large amounts of hazardous goods through great distances. In Western Europe, the length of transmission networks is estimated to be about 180 000 km for gas (natural gas), 31 000 km for oil products and 10 000 km for other chemical substances. Although most of these hazardous goods are in the scope of the Seveso II Directive, this Directive does not apply to land transmission pipelines... According to several accidents analysis, pipelines accidents may have a gravity equivalent to major accidents from fixed installations. This statement motivates EC members to have safety directive as Seveso II directive.

In this context, the French Ministry of Economy, Finance and Industry (MinEFI), which is the national authority in charge of land transmission pipelines safety, mandated INERIS to perform a study about control of major-accident hazards involving these pipelines.

The paper will give some preliminary results based mostly on a state of the art study of risk assessment on transmission pipeline. These items are presented according to four key items related with major-accident hazards on pipelines, learning from experience on pipeline accidents, damage prevention measure, satellite surveillance and consequence calculation.

1 Learning from experience and risk comparison

An overview of the literature on pipeline accident analysis over the last thirty years was performed, with accidents from France (BARPI), Europe (EGIG, CONCAWE), North America (US DOT), and former Soviet Union (VNIIGAS) and with a review conducted by Papadakis [1] in 1999 for the EU.

Statistics show that both gas and oil pipelines have caused major accidents. For example, in 1989, in former Soviet Union, more than 500 fatalities were caused by an oil pipeline rupture and in 1984, in Peru 3000 persons were evacuated because of a tetraethyl pipeline rupture. Pipelines are therefore considered as a source of industrial major-accident hazard [1,2].

The HSE [4] has noticed that main causes of failure in Western Europe are:

- Mechanical failure (fault in construction or fault in material quality) - 28 % of total causes
- Operational failure (excessive pressure or malfunctions of equipment) - 4 % of total causes
- Internal or external corrosion - 16 % of total causes due mainly to the network ageing
- Natural hazards - 2% of total causes
- Third Party activity - 41 % of total causes

Considering the number of accidents and the relative experience of each database, several authors estimated failure rates and victims rates. From such state of the art, orders of magnitude of accident frequency varying approximately from 10^{-4} to 10^{-3} per km-year and rate of victims (fatalities, injuries...) about 10^{-5} to 10^{-4} per km-year may be considered in Europe, for gas and oil pipeline.

After these observations, it was decided to compare risk due to pipelines with risk of fixed installations and hazardous goods transportation in France and in the EU. The final use of such a comparison aims to help authorities to balance the requirement of the new pipeline regulation with regards to several technological risk levels and with regards to requirements of the regulations in such fields.

Different questions are raised for the study: How to compare risks? Which approach is relevant? Which risk indices should be used? An historical approach is used to achieve the objective to get a global view of the risk level for an industrial sector at the scale of the country. The comparison is based on accident gravity and on major and fatal accident frequency. These events are well-notified [10].

With regard to gravity, pipelines have a similar potential of major accident to the fixed installations [1,2]. With regard to accident frequency, the accident rates estimated for the Seveso II sites in the EU vary from 3.10^{-3} to 7.10^{-2} major accidents per installation per year and the best order of magnitude estimate would be of 10^{-2} major accidents per year per site [11]. From the literature [1,2], a fatal accident rate of 10^{-5} per km-year for pipelines can be considered. However, notice that these estimates are attempted despite lack of detailed data [11], and do contain various uncertainties [10]. Moreover, these estimates may not be used for such basic comparison due to the significant difference between a fixed installation and a pipeline kilometre.

Thus, risk indices at the global scale of the country and for the industrial sector would be more relevant as they contain variety of context, and because they should be useful only to global decision-makers [10]. Considering the environmental regulations such as Seveso II Directive focusing on protecting public in the neighbourhood, one may consider the estimates for France of 3 fatalities per year in the public due to fixed installations (1992-2002 observation period) whereas one fatality every two years due to pipelines (1970-2000 observation period). As a reminder, these results could be tricky with regards to low frequency-high consequence events such as Toulouse disaster in France in 2001 with 8 fatalities in the public, and show once again the lack of robustness of such estimates for this type of events.

After this extract of preliminary results, the next step will be to analyse statistics available for the various means of hazardous goods transportation, pipeline, rail and road. The risk criteria to use for the comparison between transportation means will be easier, because it is possible to work on a common basis, the quantity of transported material. Also, societal risk indices as F/N curves will be used.

2 Damage prevention measures

Damage prevention measures are often required when pipelines are located in a vulnerable zone as densely populated zone, road or rail crossings, water catchments, rivers... The learning from experience showed that third party activity is the main cause of failure [4]. A review of safety measures against third party activity with earth-moving machinery was done, in order to quantify risk reduction brought by their use. Risk reduction may affect frequency of failure or consequences extent of an accident alike reducing the size of the spillage. Main data come from UK databases analysis and experiments [4]. These measures can be either technical (mechanical protection), or related to safety in operation. They can be implemented at various states of the process :

- Design : depth of cover increase, route choice, wall material choice, wall thickness...
- Construction : mechanical protection like concrete sleeves or steel plate, warning tape...
- Operation : walk, road, air observation increased, spillage detection system, information to the public or to earth moving engine users...

A study of the literature on 5 damage prevention measures is reported below.

1. The influence of depth of cover

Several studies were made to estimate the influence of the measure with various results. A HSE report [4], mentioned the following results: Knight and Grieve, concluded that increasing cover from 0,93 m

(3 ft) appeared to have little effect on the vulnerability of pipelines to external interference. Neville (1981) conducted further work in this area and concluded that an increase in depth from 0,93 m (3ft) to 1,22 m (4ft) resulted in a 38% reduction in the incident rate and to 1,6 m (5,25ft) resulted in a 64% reduction. Fearnehough and Corder, 1989, concluded that 50% of the damages were concentrated in the 30% of pipelines with a depth of cover less than 1,05 m. Furthermore, BG Transco data show that increasing the depth of cover from 1,1 to 2 m has reduced the mechanical damage frequency by a factor of 6. In different perspective, Gasunie, [6] distinguished depth dependent activities (piling, drilling, hot taping...) to depth independent activities (cable laying, drainage activities, ditch cleaning...) in rural or suburban area. In extrapolating data, relations below were developed for suburban area. For depth dependent activities failure rate $F= e^{-1,8 d -3,8}$ per km-year where 'd' is the depth of cover and d< 2 m. For depth independent activities $F= 6,2\ 10^{-4}$ per km-year.

The influence of depth cover is stated. However, a drawback of this measure when it is advocated to face a modification of the pipeline environment during its operation, is its technical difficulty to implement.

In France, by present law, depth of cover must be over 0,8 m, but this value may be increased to 1 m in the future regulation.

2. The influence of wall thickness increase

In Europe, the Institution of Gas Engineers makes recommendations for high-pressure minimum wall thickness of gas transmission pipelines [4]. In France, a formula giving a relationship between thickness, diameter, pressure, and steel properties is given in the regulation and used by operators. The scarce data available to estimate the influence of this measure show that increasing wall thickness lowers the failure rate [4]. In France, there was a case where population density was increased in the vicinity of the pipeline and required a modification of the pipeline. The authorities agreed to not replace the pipeline because of its increased thickness in accordance with the regulation.

3. The influence of mechanical protection

The British Gas [6] designed and executed a series of experiments involving a range of excavating engines and several techniques of pipeline protection. The approach used was to bury protected sections of pipeline and to ask operators, who were not informed of the presence of the pipeline, to dig as usual. As an interesting conclusion, warnings tapes are shown to have a relatively small effect used alone but are extremely effective when combined with protective barriers like concrete sleeves.

4. The influence of third party information

According to CONCAWE data, a major part of accidents, 65%, result on the ignorance of the pipeline location, especially in case of non-notified works. The other causes result on a negligence of the third party operator. Pipeline signalling and third party information are among the most important preventive measures [7]. Setting markers on the pipeline route is a standard practice in all European countries. Information of the third party activity can vary according to the country, from one phone call system to few meetings with local authorities. No review was found on the effectiveness of such systems.

5. The influence of air surveillance, mobile/walking monitoring

All operators commonly use monitoring. It allows monitoring the global aspect of the pipeline, detecting potential non-notified works or detecting leakage by apparition of oil on the ground or modification of the ground aspect. The efficiency of the monitoring will change with the frequency, but it is difficult to say if there is a change between a weekly monitoring and a twice-monthly monitoring. New technology using satellite monitoring will be developed later in this paper.

After this state of the art study, INERIS intends to develop a methodology to assess risk reduction benefits.

When it was possible for the authors in the literature, risk reduction brought by damage prevention measures were quantified. It could correspond to a failure rate reduction or to a consequence extent reduction as a decrease of the leak size: breach diameter, leak duration.

Starting point of this methodology is to define a reference state for the pipeline that corresponds to maximum risk acceptability. It could be the risk induced by the same pipeline in a rural area with no specific risk as specific agricultural work, important corrosion and with low vulnerability of the targets. Then, starting in the situation of the pipeline without any prevention measures, the influence of all measures used or proposed will be estimated. The aim is to reach the reference state with all safety measures set. If this is not the case, additional measures have to be defined. The main methodology difficulty is the risk reduction quantification of some safety barriers that can be quantitative, semi-quantitative or qualitative. Some results will be agreed in a French work group composed of main pipeline operators to study the effect of damage prevention measures. The main purpose is to write a guideline recognised by law to inform operators and help them to choose whether damage prevention measure to use in several case.

3 Satellite surveillance

Remote satellite technology can provide a new way to monitor pipelines for a better detection of earth-moving machinery, ground movement or leaks. INERIS defined specifications for such a monitoring with Spotimage and Gaz de France. Spotimage is specialised on satellite imagery and Gaz de France participates to a European research project: Pipeline **RE**mote **SENs**ing for Safety and the Environment, PRESENSE, that aims to assess the potential benefits of these technologies. PRESENSE [12] gathers European gas operators, European Space Agency and companies specialised in data processing technologies.

One of the technical conclusions of the exchanges with Spotimage is that present technology can not fulfil the requirement of earth-moving machinery detection near pipeline. Some reasons are exposed below:

- Necessary high frequency of flying over requires an important mean of data treatment with inevitably high costs,
- Data transmission times are incompatible with immediate risk characteristic of third activity near pipeline,
- Cloudy weather disables the process. Therefore, in Europe, all areas can not be covered at all times. To improve that, Radar technologies can be used but they are very costly and not directly usable,
- Actual precision of civil imagery, about 10 m does not allow to detect precisely all kind of engine.

Gaz de France conclusions on PRESENCE project are:

- Satellite surveillance is a long-term promising technology even if this application has to be more clearly defined,
- In a global view, this technology can be used in a local situation but not in a global one,
- Used alone, this technology does not seem economically affordable. It has to be combined with other monitoring technologies often used by operators of underground network (water, cable, electricity...).

4 Evaluation of consequences

Evaluation of risk includes consequence assessment on human health and environment in case of accidental releases from a pipeline. Calculations should be performed for several typical configurations (materials, pipelines diameter, pressure...). The TNO report called "Methodology for selection of pipelines which potentially can cause a major hazard" [8] is a state of reference in the EU on the subject. Therefore, the first step for INERIS was to study this report. INERIS made some comments on the methodologies or models used hypothesis taken and lethality threshold chosen. These comments aim to advise the MinEFI on how to interpret the TNO results. Second step was to compare TNO and INERIS results with the same hypothesis but with INERIS models for effects calculation. Third step was to remake calculations with hypothesis used on pipeline safety studies in France and models used at INERIS. Fourth and last step is to remake calculations with hypothesis taken in safety studies on fixed installations required by the French regulation.

TNO study is based on:

- A classification of materials in function of the hazard it represents (toxic, **flammable...**),
- A representative substances for each category of hazard (chlorine for **toxic...**)
- Specific pipeline characteristics (**diameter...**),
- **Specific** transport conditions in term of pressure and temperature,
- Specific conditions of leakage (time of leakage, leakage after isolation of the section).

A pipeline is considered to potentially cause a major hazard for the TNO, if distance of effects corresponding to 1% of lethality is over 100 m, or if more than 10 000 m^3 of ground are polluted.

As an example of the study, the table 1 shows some results and the differences between INERIS and TNO simulations, for same pipelines and products with same hypothesis but by changing only models used.

Table 1: Results of INERIS simulations for a selection of pipeline that can be hazardous

Hazard category	Type of substance	**diameter**< 6"			6" < diameter **<12"**			diameter > 12"		
		Pressure (bar)			Pressure (bar)			Pressure (bar)		
		< 10	10-25	> 25	< 10	10 - 25	> 25	< 10	10 - 25	> 25
Highly toxic	Acrolein L	+	+	+	+	+	+	+	+	+
	Phosgene LG	+	+	+	+	+	+	+	+	+
Toxic	**Acrylonitrile** L	+	+	+	+	+	+	+	+	+
	Carbon Monoxide G	+	+	+	+	+	+	+	+	+
	Chlorine LG	+	+	+	+	+	+	+	+	+
flammable	Ethyl Benzene L	-	-	-	+	+	+	+	+	+
Highly flammable	Petrol L	+	+	+	+	+	+	+	+	+
Extremely flammable	Propylene oxide L	+	+	+	+	+	+	+	+	+
	Hydrogen G	-	+	+	+	+	+	+	+	+
	Propane LG	-	-	-	+	+	+	+	+	+
Oxygen	Oxygen G	-	-	[illegible]	-	-	[illegible]	[illegible]	[illegible]	[illegible]

L = liquid; LG = liquefied pressurised gas; G = gas.

\+ Pipeline that could potentially generate a major accident

\- Pipeline that is not considered as a pipeline with major risk

Greyed cells represent a difference between INERIS and TNO simulations.

This table shows that 80 % of the simulations produce same conclusions for INERIS and TNO. A few differences in particular for hydrogen, propane and oxygen are identified. For hydrogen, unlike the TNO, INERIS considers UVCE scenario because of the explosion potential of hydrogen cloud (an immediate ignition is not considered). For propane, unlike the TNO, INERIS has rather chosen UVCE scenario than BLEVE scenario. For oxygen, the **flammability** risk is considered with an increase to 30 % of oxygen in volume. INERIS found no effect at 1,5 m high for a vertical release due to important air mixing.

Then, using INERIS models and hypothesis of French safety studies on pipeline (**GESIP** guidelines, **[9]**), some differences are found, with carbon monoxide that is not considered to be a hazardous material contrary to TNO results. Petrol appears to INERIS to be non-hazardous for health effects only for under 6" diameter pipeline.

The aim for these simulations is to compare methodologies of calculation and to see the influence of various parameters in simulation. First of all, this study aims to help the MinEFI to widen or not the scope of the future regulation that will define which pipelines and materials should be assessed within safety studies according to risk of major accident.

Secondly, it will help to define the distances from the pipeline where the risk exposure of the environment and its targets will have to be assessed.

5 Conclusion and perspectives

Pipelines are fixed installations that carry hazardous materials on large distances from a point to another crossing, as well, public and private areas. Fixed installations are regulated by Directive 96/82/CE known as Seveso II Directive that requires the operators of industrial facilities using hazardous materials to develop a major accident prevention policy and a Safety Management System (SMS) in order to prevent major accidents. Pipelines are not in the scope of this directive. Whereas comparing risk due to fixed installations and risk due to pipeline is complex some studies show that pipelines can be a major hazard accident source as for Seveso sites [1]. Therefore, the European Commission considers a similar approach trough a future directive for land transmission pipeline that can cause major accident. Thus, pipelines that will be covered by this directive have to be identified. The TNO has issued a report [8] to select those pipelines. To transfer these results into the French context, INERIS has reviewed this report to advise the MinEFI before issuing a new regulation.

Thereafter the identification of pipelines, the application of such type of directive requires developing an approach with the step of identification of accident scenarios for risk evaluation and the step of risk control by operators. The first step goes by specifying the assumptions and the conditions of occurrence of the scenarios to assess in safety studies. It can be based on learning from experience and on evaluation of consequence extent. Some items on these subjects were exposed in this paper. Once hazards acknowledged, the second step requires reaching an acceptable risk level to demonstrate risk control. By the way, that will require quantifying risk reduction brought by prevention measures. INERIS intends to develop with operators in France a methodology to assess risk reduction benefits especially against third party activity that is the main accident cause. This methodology is based on the literature study of several measures commonly used by operators. Five measures are presented in this paper and in particular pipeline satellite monitoring. With the actual state of the art (presented in main terms in this paper) the risk reduction quantification is not completed for all measures. This can be achieved by setting up expert work groups, carrying out experiments and simulations and learning from experience at national and EU levels. Notice that no pipeline disaster occurred in the EU for recent years that enable a co-operative working context between stakeholders to issue a new regulation (low media pressure, no urgency).

However, to reach this objective of risk control, a main question stays in mind: who is going to define this level of residual risk acceptance in France or in the EU and with which criteria. Moreover this risk level should be discussed at a local level for decision making in accordance with the local context and environmental vulnerability. Same criteria as for fixed installations may not be used. As an example, in France, for land use planning stemming from the definition of this level, the regulation requires that there are a very few existing houses in the lethal effect area. The same requirement for pipelines in France would be equal to "freeze" an area of approximately 3% of the French territory that is not conceivable.

6 Reference

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