SAFETY IN EUROPEAN GAS TRANSMISSION PIPELINES
EGIG: EUROPEAN GAS PIPELINE INCIDENT DATA GROUP

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ABSTRACT

The use of pipelines for the transport of large quantities of natural gas to industry and to commercial and domestic consumers represents a safe mode of transport in terms of impact on the environment and human health. As a general policy the natural gas industry strives to achieve one main objective: the construction, operation and maintenance of safe pipeline systems.

In 1982 six European gas transmission system operators took the initiative to gather data on the unintentional releases of gas in their transmission pipelines systems. This cooperation was formalised by the setting up of EGIG (European Gas pipeline Incident data Group). The objective of this initiative was to provide a broad basis for statistical use, thus providing a more realistic picture of the frequencies and probabilities of incidents than would have been possible with the independent data of each company considered separately. Nowadays, EGIG is a cooperation of twelve major gas transmission system operators in Europe and it is the owner of an extensive database of pipeline incident data collected since 1970.

Uniform definitions have been used consistently over the entire period. Consequently, on condition that the data is correctly used and interpreted, the EGIG database gives useful information about trends which have developed over the years. Indeed, the EGIG report demonstrates the safety performances of the existing transmission pipeline system in Europe and also provides a broad basis for statistical use.

This paper introduces the EGIG database and presents the most important data analyses and their results. The results of the analyses are commented on and give the most interesting information that can be extracted from the database. Linking of results of different analyses takes place when possible.
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INTRODUCTION

The use of pipelines for the transport of large quantities of natural gas to industry and to commercial and domestic consumers represents a safe mode of transport in terms of impact on the environment and human health. The safety and the protection of the environment are constant objectives in the policies about construction, operation and maintenance of pipeline systems of the European natural gas industry. One way to monitor the safety of pipeline systems is to collect and analyze the data concerning the unintentional gas releases.

In 1982 six European gas transmission system operators took the initiative to gather data on the unintentional releases of gas in their transmission pipe lines systems. This cooperation was formalised by the setting up of EGIG (European Gas pipeline Incident data Group). The objective of this initiative was to provide a broad basis for statistical use, thus providing a more realistic picture of the frequencies and probabilities of incidents than would have been possible with the independent data of each company considered separately. Nowadays, EGIG is a cooperation of twelve major gas transmission system operators in Europe and it is the owner of an extensive database of pipeline incident data collected since 1970. In the period between 2001 and 2004 three new major gas transmission companies from Czech Republic, Portugal and Finland has become an EGIG member. The participating companies are nowadays the following:

- DONG (Denmark)
- ENAGAS, S.A. (Spain)
- Fluxys (Belgium)
- Gasum (Finland)
- N.V. Nederlandse Gasunie (The Netherlands)
- Gaz de France Réseau Transport SA (France)
- Ruhrgas AG (Germany)
- SNAM Rete Gas (Italy)
- SWISSGAS (Switzerland)
- National Grid* (UK)
- Transgas (Czech Republic)
- Transgas (Portugal)

Considering the number of participants, the extent of the pipeline systems and the exposure period involved, the EGIG database is a valuable and reliable source of information. In 2004 the total system exposure was equal to 2.77 million km.yr.

This paper is based on the official sixth EGIG report [1] covering the period 1970-2004. It introduces the EGIG database and presents different analyses and their results. The results of the analyses are commented on and give the most interesting information that can be extracted from the database. Linking of results of different analyses takes place when possible. The EGIG report is annually updated and is available on the following internet site: www.EGIG.nl.

* was Transco, part of National Grid Transco, at time of data collection
1. EGIG DATABASE

The objective of the EGIG database is to get and maintain a valuable and reliable source of information about incident data on natural gas transmission pipelines, which gives the opportunity to demonstrate the continuing high safety level of the European gas transmission pipelines system and to provide a broad basis for statistical use.

The required criteria for an incident to be recorded in the EGIG database are the following:
- The incident must lead to an unintentional gas release,
- The pipeline must fulfil the following conditions:
  - To be made of steel
  - To be onshore
  - To have a design pressure higher than 15 bar
  - To be located outside the fences of the installations

Incidents on production lines or involving equipments or components (e.g. valve, compressor) are not recorded in the EGIG database.

The EGIG database contains general information about the major European gas transmission pipelines system as well as specific information about the incidents.

General information about the pipeline system is given per year on pipeline length categorised according to:
- Diameter
- Pressure
- Year of construction
- Type of coating
- Cover
- Grade of material
- Wall thickness

Specific information about incident comprises:
- The characteristics of the pipeline on which the incident happened, namely the general information listed here above.
- The leak size:
  - Pinhole/crack: the diameter of the hole is smaller than or equal to 2 cm
  - Hole: the diameter of the hole is larger than 2 cm and smaller than or equal to the diameter of the pipe
  - Rupture: the diameter of the hole is larger than the pipeline diameter.
- The initial cause of the incident
  - External interference
  - Corrosion
  - Construction defect/material failure
  - Hot tap made by error
  - Ground movement
- Other and unknown

- The occurrence (or non-occurrence) of ignition
- The consequences
- Information on the way the incident has been detected (e.g. contractor, landowner, patrol)
- A free text for extra information.

Additional information is also given for the individual cause:

- External interference:
  - The activity having caused the incident (e.g. digging, piling, ground works)
  - The equipment involved in the incident (e.g. anchor, bulldozer, excavator, plough)
  - The installed protective measures (e.g. casing, sleeves)

- Corrosion:
  - The location (external, internal or unknown)
  - The corrosion type (galvanic, pitting, stress corrosion cracking “SCC” or unknown)

- Construction defect/material failure:
  - The type of defect (construction or material)
  - The defect details (hard spot, lamination, material, field weld or unknown)
  - The pipeline type (straight, field bend, factory bend)

- Ground movement:
  - The type of ground movement (dike break, erosion, flood, landslide, mining, river or unknown).

- Other and unknown:
  - The sub-causes out of category such as design error, lightning, maintenance.

2. ANALYSES AND RESULTS

The objective of data or statistical analysis is to interpret the information contained in the data in order to draw conclusions from the sample or the population from which the sample is taken.

The statistical analyses about the safety level of the gas transmission pipelines system are based on the calculation of indicators such as failure frequency, (mean or deviation) and ignition probability.

The failure frequency is calculated by dividing the number of incidents by the exposure. The EGIG report presents two kinds of failure frequencies, the primary and the secondary. They refer to the notions of total and partial exposure respectively. These notions are defined below.

- Exposure is the length of a pipeline and its exposed duration and is expressed in kilometres-years [km.yr]. Example: company A has a constant length of transmission pipelines over 5 years of 1,000 km. Its exposure is then 5 times 1,000 km, so 5,000 km.yr.

- The total system exposure is the exposure as defined above, calculated for the complete system.

- The partial system exposures are the exposures calculated per design parameter, e.g. per diameter class or per depth of cover class.

The failure frequencies are calculated by dividing the number of incidents by a system exposure.
In order to distinguish safety improvements of the last period a 5-years moving average has been introduced. The 5-years moving average means that the calculations have been performed over the 5 previous years in question.

Two statistical terms are also used in this paper, confidence interval and ageing analysis:

- A confidence interval gives an estimated range of values which is likely to include an unknown population parameter, the estimated range being calculated from a given set of sample data. A confidence interval at 95% means that there is 95% probability that the real value (so not the estimated one) of the failure frequency lies in this interval.
- Ageing is the process of growing old and showing the effects of increasing age. For EGIG purposes an ageing analysis has been carried out in order to study the impact of the age of the pipelines on their failure frequencies. This analysis was made by comparing the failure frequencies of different pipeline age categories.

2.1 Trends of the European gas transmission system

This paragraph gives information on the European gas transmission system from 1970 up to the present.

2.1.1 Total length

The total length of the European gas transmission pipelines system in EGIG is constantly increasing. In 2004 the annual length was equal to 122,168 km against 110,236 km in 2001. The evolution of the total length of the system is shown in figure 1.

![Figure 1: Total length of the European gas transmission system in EGIG](image-url)
Figure 1 shows a linear increase in the length of the European gas transmission system in EGIG, which has step changes in the years 1975, 1991, 1998 and 2003. These changes correspond to new members joining the EGIG.

2.1.2 Exposure

Figure 2 shows the increase of the exposure over the years. For the period 1970-2004, the total system exposure was equal to 2.77 million km.yr. The increase is due to year-to-year experience built up and the EGIG participation of new operators in Europe.

![Figure 2: Evolution of the exposure](image)

2.2 Failure frequencies analyses

This paragraph deals with the calculation of safety indicators, namely the primary and secondary failure frequencies. These calculations refer to three notions: the total system exposure, the partial system exposure and the number of incidents.

2.2.1 Number of incidents

In the fifth EGIG report, which covers the period 1970-2001, a total of 1,061 incidents were recorded. In the last three years 62 incidents were reported by the EGIG members, which brings the total number of incidents to 1,123 for the period 1970-2004. Figure 3 shows the number of incidents per year and figure 4 the cumulative number of incidents.
2.2.2 Primary failure frequencies

The primary failure frequency is the result of the number of incidents within a period divided by the corresponding total system exposure. Depending on the period studied, the number of incidents varies and so does the total system exposure.
The EGIG has compared the primary failure frequencies of different periods, namely the total period (1970-2004), the period corresponding to the fifth EGIG report (1970-2001), the period of the last 5 years (2000-2004) and the final year.

The primary failure frequencies of these periods are given in Table 1.

<table>
<thead>
<tr>
<th>Period</th>
<th>Number of incidents [-]</th>
<th>Total system exposure [km.yr]</th>
<th>Primary failure frequency [1000 km.yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970-2001</td>
<td>1061</td>
<td>$2.41 \times 10^6$</td>
<td>0.44</td>
</tr>
<tr>
<td>1970-2004</td>
<td>1123</td>
<td>$2.77 \times 10^6$</td>
<td>0.41</td>
</tr>
<tr>
<td>2000-2004</td>
<td>100</td>
<td>$0.57 \times 10^6$</td>
<td>0.17</td>
</tr>
<tr>
<td>2004</td>
<td>23</td>
<td>$0.12 \times 10^6$</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Table 1: Primary failure frequencies

An observation from Table 1 is that the primary failure frequency (0.41) over the entire period (1970-2004) is slightly lower than the one (0.44) of the period 1970-2001.

The failure frequency over the past five years (0.17 for 2000-2004) is equal to less than half of the primary failure frequency over the entire period showing the improved performance over recent years. Another observation is that the primary failure frequency over the last year (0.19 for 2004) is slightly, but not significantly, higher than the failure frequency of 0.17 calculated over the last 5 years (2000-2004).

Figure 5 and Figure 6 show the evolution of the primary failure frequencies over the entire period and for the last five years, as well as the confidence intervals at 95%.

Figure 5: Evolution of the primary failure frequencies
Figure 5 illustrates the steady drop of the primary failure frequencies and the failure frequencies of the 5 years moving average. The primary failure frequency over the entire period declined from 0.87 per 1,000 km.yr in 1970 to 0.41 per 1,000 km.yr in 2004. The moving average primary failure frequency over five years decreased by a factor 5 (0.86 to 0.17 per 1,000 km.yr).

Figure 6: Primary failure frequencies and confidence intervals at 95%

Figure 6 shows the confidence intervals for the primary failure frequency.

**Remark**

A confidence interval is made to take uncertainty into account. We see that the greater the exposure, the smaller the interval, which, logically, means that the uncertainty decreases if the quantity of information increases. To calculate a confidence interval the population is assumed to have a known distribution. Most used and common distributions are Gauss’ law (normal distribution), Poisson’s law, the binomial distribution or the exponential one. The number of incidents, being a whole number (discrete,) is small in comparison to the exposure. The assumption is made that the number of incidents follows Poisson’s law, also called law of rare events.

In 2004 the primary failure frequency over the entire period was equal to 0.41 per 1,000 km.yr with a 95% confidence interval of ± 0.02. The primary failure frequency over the last five years was, in 2004, equal to 0.17 per 1,000 km.yr with a 95% confidence interval of ± 0.03.

Other interesting information is the distribution of the incidents per cause. Six different causes have been identified and are given below in association with the percentage of incidents they represent:

- External interference : 50%
- Construction defect / Material failure : 17%
- Corrosion : 15%
- Ground movement : 7%
- Hot-tap : 5%
- Other and unknown : 7%
Figure 7: Distribution of incidents per cause

Figure 8 and Figure 9 give respectively the primary failure frequencies for the entire period (up to the year) and for the last five years moving average per cause.
Figure 9: Primary failure frequencies per cause (5-years moving average)

Figure 8 and Figure 9 also illustrate the reducing failure frequency over the years. This has been due to technological developments, such as: welding, inspection, condition monitoring using in-line inspection and improved procedures for damage prevention and detection.

As far as the cause of external interference is concerned, its associated primary failure frequency over the period 1970-2004 decreased to 0.20 per 1,000 km.yr while the 5-years moving average has levelled off at around 0.10 per 1,000 km.yr since 2000. However external interference remains the main cause of incidents.

A further improvement in the prevention of external interference could be obtained through a more stringent enforcement of land use planning and the application of one-call systems for the digging activities of external parties.

The EGIG was interested in the relation between the age of the pipelines and their failure frequencies. In other words, the EGIG wanted to know if old pipelines fail more often than younger ones. The influence of the age of the pipelines on their failure frequencies has been studied in the ageing analysis presented in Figure 10.
**Figure 10: Ageing analysis (corrosion and construction defects)**

**Explanation Figure 10**

Taking for instance a pipeline constructed in 1970 (Construction year 65-74), the failure frequency after 5 years (1975) will equal 0.15 whereas it will equal 0.08 after 30 years (2000).

The first conclusion of Figure 10 is that early constructed pipelines have indeed a higher failure frequency than recently constructed pipelines. The second very important conclusion is that all failure frequencies irrespective of the age category are slightly decreasing in time.

The EGIG has been interested in the relation between the causes and the damage size. Figure 11 illustrates the link between the causes and the type of incident in terms of size of leak.

**Figure 11: Relation cause-size of leak**
Figure 11 shows that the bigger leak sizes (holes and ruptures) are caused by external interference, which is also the most common cause (50% of the incidents).

The external interference activities causing most incidents are those, which involve excavators for digging (39%), drainage works (8%), public works (8%), and the activities related to agriculture (8%).

2.2.3 Secondary failure frequencies

The secondary failure frequencies are calculated by dividing the number of incidents by a partial system exposure. Partial system exposure means, for example, the exposure related to one diameter class or one year of construction.

The calculation of secondary failure frequencies is meant to observe the influence of 'design parameters' (pressure, diameter, depth of cover, etc.) on the causes and consequences of the incidents.

Relation between external interference size of leak and design parameter

Figures 12 to 14 show the relation between the consequences of the incidents caused by external interferences and the diameter of the pipeline, the depth of cover and the wall thickness. Although the graphs are presented separately it must be noticed that the design parameters are correlated.

Figure 12: Relation external interference size of leak and diameter class
From these figures some general conclusions can be drawn. The first conclusion is that small diameter pipelines are more vulnerable to external interferences than bigger diameter pipelines. This can be explained by the fact that small diameter pipelines can be more easily hooked up during ground works than bigger pipelines, the second reason is that their resistance is often lower due to thinner wall thickness.
**Relation between corrosion size of leak and design parameter**

Figures 15 to 17 show the relation between the leak sizes of the incidents caused by corrosion and the year of construction of the pipeline, the type of coating and the wall thickness.

**Figure 15: Relation corrosion size of leak and year of construction**

**Figure 16: Relation corrosion size of leak and type of coating**
Corrosion has been identified as the third cause of incident (15%). Study of figures 15 to 17 shows that corrosion often results in smaller leak sizes (pinholes and cracks), whereas very few holes were observed and only one rupture occurred on a pipeline, which was constructed before 1954.

Figures 15 illustrates the link between the year of construction of the pipelines and the failure frequencies whereas figure 16 shows the relation between the type of coating and the failure frequencies. From these figures it can be concluded that the older the pipeline, which generally used bitumen and coal tar, the higher the failure frequencies are.

Corrosion is a phenomenon of deterioration of the pipelines. Corrosion takes place independently of the wall thickness, but the thinner the corroded pipeline wall, the sooner the pipeline fails, as figure 17 illustrates. The failure point of a thinner pipeline is reached more quickly. Corrosion on thicker pipelines takes longer before causing an incident and therefore has more chance to be detected. Different protective measures are undertaken by pipeline owners to overcome the problem of corrosion. These measures are for example cathodic protection and pipeline coating. In line inspections and pigging operations also allow detecting corrosion at early stage.

Three types of corrosion have been addressed by the EGIG: external corrosion, internal corrosion and corrosion with an unknown cause. Up to 2004 they represented respectively 79%, 16% and 5% of all incidents due to corrosion. 71% of the cases of external corrosion was due to pitting. Galvanic corrosion and unknown causes represented both 13% of the external corrosion incidents whereas stress corrosion cracking was responsible for only 2%.
Figure 18 shows that the older the pipelines, the higher the failure frequencies (due to construction defect/material). It seems that the new pipelines are less vulnerable to construction defect/material, which is synonymous to technical improvements. This phenomenon has already been observed in the ageing analysis.

2.3 Detection of incidents

Figure 19 shows the distribution of the type of detection. With almost 40% of all incidents detected, the public is the most common detector. Up to 2004 almost 20% of the incidents were detected by the patrols, which demonstrates their usefulness and effectiveness.
2.4 Ignition probability

Fortunately not every gas release ignites, which seriously limits the consequences of the incidents. In the period 1970-2004, only 4.1% of the gas releases recorded as incidents in the EGIG database ignited.

Ignition depends on the existence of random ignition sources. The EGIG database gives the possibility to evaluate the link between ignition and leak size. Table 2 gives the ignition probabilities per size of leak.

<table>
<thead>
<tr>
<th>Size of leak</th>
<th>Ignition probabilities [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinhole-crack</td>
<td>3</td>
</tr>
<tr>
<td>Hole</td>
<td>2</td>
</tr>
<tr>
<td>Rupture &lt;= 16 inches</td>
<td>9</td>
</tr>
<tr>
<td>Rupture &gt; 16 inches</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 2: Estimated ignition probabilities per leak type

Table 2 clearly shows that gas releases from big diameter pipelines are more likely to ignite than releases from smaller diameter pipelines. It can be noticed that the larger diameter pipelines are also more likely to be higher in pressure.

This table gives the ignition probabilities of all incidents together no matter their causes. It is obvious that these probabilities vary according to the causes. The EGIG specifically looked at the ignition probabilities of gas releases caused by lightning.

Out of 18 gas releases in the period 1970-2004, 9 ignited, which brings the ignition probability of gas releases due to lightning up to 50%.
CONCLUSION

EGIG has maintained and expanded the European gas pipeline incident database. Transmission companies of twelve European countries now collect incident data on more than 122,000 km of pipelines every year. The total exposure, which expresses the length of a pipeline and its period of operation, is 2.77 million km.yr.

The statistics of incidents collected in the database give reliable failure frequencies. The overall incident frequency over the period 1970 to 2004 is equal to 0.41 incidents per year per 1,000 km.

The 5 year moving average overall failure frequency, which represents the average incident frequency over the past 5 years, equals 0.17 per year per 1,000 km. This frequency is almost 5 times lower than the one reported in the first years of the database (1970-1974).

The failure frequencies have been reducing consistently over the years, although they recently tend to stabilize.

The major cause of incidents remains external interference (50% of all incidents), followed by construction defects/material failures (17%) and corrosion (15%). Over the past five years, 51% of all incidents were due to external interference. The relatively high contribution of external interference emphasises its importance to pipeline operators and authorities.

External interference incidents are characterised by potentially severe consequences (holes and ruptures), and the incident in Ghislenghien on 30 July 2004 reminds us of this fact.

REFERENCES