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# Safety and Integrity of Pipeline Systems - Philosophy and Experience in Germany





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## Abstract

The design, construction and operation of gas pipeline systems in Germany are subject to the Energy Act and associated regulations. This legal structure is based on a deterministic rather than a probabilistic safety philosophy, consisting of technical rules implemented by the gas industry itself and operator responsibilities. Governmental institutions only have a general supervisory function. This deterministic approach is aimed at achieving maximum primary safety. Citing various examples, this paper describes a number of measures. With a special methodology developed as a software package, it will in future be possible to use budget funds for operational safety programmes in such a way that maximum primary safety is achieved. A review of the deterministic and probabilistic safety philosophies in Europe shows that both have produced equally high quality levels. Standardising these philosophies as part of the European integration process would place an additional cost burden on the various gas industries without improving safety levels in a way that would justify these expenses. It is therefore legitimate to retain the different systems that have evolved in the individual countries for different historical reasons.

## Safety Philosophies

For the purpose of ensuring a high safety level of high-pressure gas pipelines, various safety concepts have proved their worth. They can be divided into two groups: those based on a probabilistic safety philosophy and others having a deterministic orientation. There is no clear-cut dividing line between the groups, but each of them has certain distinguishing features.

### Probabilistic Philosophy

In the probabilistic philosophy, "risk" is at the forefront of all considerations. To determine this risk, possible negative consequences are quantified in a risk analysis, multiplied by the estimated probability of occurrence and then aggregated. Different technologies for performing a function, i.e. the transmission of gas, result in the calculation of different risk values despite identical external conditions, such as terrain and population density. The lower the figure, the more reliable the respective technical solution is considered in relation to others. With this method, the problem of how to deal with the possibility of an incident that cannot be ruled out despite optimum precautions is shifted to the debate on the tolerable risk threshold.

Risk analyses have variously gained the image of being a transparent procedure for objectively ascertaining the hazard posed by a particular technology. Yet it is frequently overlooked that basic parameters needed to calculate the risk, such as the probability of occurrence of incidents obtained from statistical material or data on the population density or location of buildings along a pipeline route, are not always sound or up-to-date. This in turn undermines the reliability of the calculations. In addition, it is very hard to convince the public at large that a technical facility having a certain calculated risk value is adequately safe. Members of the public always ask why the threshold accepted by experts is not even lower. This leads to difficult discussions because it is hard to make the calculation methods clear to the layman.

**Deterministic Philosophy**

The deterministic safety concept draws on the wealth of experience gained over the years with the use of technology. To determine effective safety measures, the chain of causal links that might lead to an undesirable incident is traced back. This investigation of causes leads to a suitable precaution designed to preclude the undesirable incident with a high degree of reliability. Such precautions are known as primary safety measures. They reduce the probability of an incident occurring. Secondary safety measures, on the other hand, serve to minimise the negative consequences of an undesirable incident that actually occurs. It is difficult to explain to the public and to consumers the need for secondary safety measures. After all, they rightly wish to assume that gas facilities are reliable from the outset and do not want to be confronted with the consequences of damage.

With the deterministic approach, decisions on the technology to use are not based on a calculated risk. Instead, experts analyse which undesirable incidents lie in the realm of possibility and what counteraction constitutes a reliable way of preventing their occurrence. In contrast to risk analysis, this method is therefore described as safety analysis.

## Deterministic Safety Philosophy in Germany

In the German gas industry, primary safety measures designed to prevent the occurrence of an incident take precedence over secondary measures in keeping with a deterministic safety philosophy. Analyses are performed to obtain information on the safety of, and not on the risk posed by, a technical facility.

Given the diversity of technical facilities in Germany, there are three categories of safety requirements:

- acknowledged rules of technology,
- the state of the art,
- the latest scientific and technical findings.

This distinction takes account of the fact that different technologies have a different hazard potential.

The hazard potential of gas facilities can be rated low for the following reasons:

- In Germany, the design, construction and operation of gas facilities, especially high-pressure gas pipelines, are based on an evolved technology which has constantly been improved in the course of at least three generations and can now be considered mature. The gas grid serves exclusively to transport and distribute natural gas, without any chemical transformation of the medium or other hazardous process engineering operations, such as fractionation, separation or conversion.
- Natural gas is a non-toxic product.
- When natural gas escapes into the atmosphere, it rises because it is lighter than air and thus does not collect at ground level. If ignited in unconfined spaces, it deflagrates without any overpressure hazardous to human beings. On sites with obstacles and in buildings, hazardous overpressure may occur, but even there detonation is impossible in

almost all cases. The heat radiation produced during a fire may cause damage to property and injury to persons. However, over the last 30 years, no uninvolved third party has been injured or killed during an incident on the high-pressure gas transmission system in Germany.

In view of these circumstances, high-pressure gas pipelines in Germany have to comply with acknowledged rules of technology, while nuclear facilities, for instance, must be in line with the latest scientific and technical findings.

Acknowledged rules of technology amount to what the majority of experts consider technically right and sensible. It is best if they are laid down in writing, but this is not absolutely essential. As acknowledged rules of technology change in the course of time and as it is necessary to retain customer confidence and achieve greater cost-effectiveness, safety concepts are constantly reviewed and improved in step with technical progress.

## Legal Foundations in Germany

### Energy Act

In Germany, the public gas supply system is subject to the Energy Act [1]. Inter alia, the latter aims at making sure that energy supplies are as secure and reasonably priced as possible. The Energy Act does not contain detailed requirements for the construction and operation of energy facilities. Even the associated High-Pressure Gas Pipeline Regulation [2] specifies only a few basic requirements. Under the Regulation, a high-pressure pipeline is deemed to comprise not only the pipeline proper but also all installations pertaining to pipeline operation, such as compressor, metering and pressure-regulating stations.

### High-Pressure Gas Pipeline Regulation

The requirements laid down in this Regulation include the following:

- pipelines must be designed to ensure proper condition and tightness;

- pipelines have to be laid in a right-of-way to maintain their integrity and must be protected against third-party damage;

- mutual interference of pipelines has to be precluded, and they must be protected against external corrosion;

- safety valves to monitor operating pressure and block valves to allow safe interruption of pipeline operation have to be installed;

- maintenance stations have to be set up to receive reports and take remedial action in the event of an incident.

In particular, the Regulation stipulates that pipelines have to be constructed and operated in accordance with acknowledged rules of technology.

It is thus clear that German legislators have mainly set out requirements aimed at guaranteeing preventive protection, i.e. primary safety, and have refrained from excessive detail. The detailing of requirements is left to private-sector specialist organisations, which define them in their own sets of rules.

**Gas Industry's Own Rules**

The detailed definition of safety requirements for the gas industry is handled by such private-sector organisations as the German Institute for Standardisation (DIN) and the German Association of Gas and Water Engineers (DVGW). The Second Regulation Implementing the Energy Act contains a so-called rule of assumption, i.e. it is assumed that acknowledged rules of technology are observed if DVGW codes of practice are applied during the design, construction and operation of the respective facility. Compliance with these codes of practice is not mandatory; deviations are possible if the same degree of safety is attained by other means, but in such a case the builder or operator bears a higher burden of proof in the event of an incident.

The two most important standards for the construction and maintenance of gas pipelines are DVGW Codes of Practice G 463 "Design and Construction of Steel Gas Pipelines for Maximum Operating Pressures in Excess of 16 bar" [3] and G 466 "Inspection, Repair and Maintenance of Steel Gas Pipelines for Maximum Operating Pressures in Excess of 4 bar" [4]. Before a gas pipeline is commissioned, compliance with the G 463 requirements is checked and certified by an independent inspector pursuant to the High-Pressure Gas Pipeline Regulation.

**Operator's Own Responsibility**

Apart from the rules concerning the operation and monitoring of facilities, as laid down in Code of Practice G 466, decisive importance attaches to the responsibility borne by operators themselves. The High-Pressure Gas Pipeline Regulation codifies the operator's responsibility as follows:

"Each high-pressure gas pipeline operator shall ensure proper condition and functioning of the pipeline, constantly survey it, carry out maintenance and repair work on said pipeline without any delay and take all safety measures as may be necessary."

Operators not only implement suitable safety measures on their own facilities, but also participate in updating and refining DIN and DVGW rules through participation of their representatives in the relevant committees. Acceptance by a broad majority of experts is required before a proposed technical rule, which must also have proved its worth in practice, can be adopted. Detailed technical requirements are thus established by the gas industry itself. Since the statutes refer to the DVGW codes of practice and the operators' own responsibility, laws and regulations do not need constant amendment. New requirements are discussed by experts and, if necessary, incorporated unbureaucratically into the dynamically evolving DVGW rules.

Public authorities merely perform a supervisory function. If necessary, they intervene to ward off particular hazards to employees or third parties. The authorities are entitled to demand information on the type, scope and results of plant surveillance performed by an operator.

This clear-cut division of tasks between public authorities on the one hand and private-sector organisations and operators on the other has guaranteed maximum safety and met with broad acceptance. It is an important feature of the deterministic safety philosophy that has become established in the German gas industry.

## Primary and Secondary Safety

One of the main reasons why public authorities have not restricted the entrepreneurial freedom created by this system is the conviction that operators of high-pressure gas pipelines have performed their functions circumspectly, with the requisite competence and in conformity with accident prevention regulations, DIN standards and DVGW codes of practice. These German rules focus mainly on the implementation of primary safety measures, such as

- a uniform design of pipelines with a design factor of 0.625, irrespective of regional classification, as found in other European countries;

- hydrostatic stress testing of pipeline sections to eliminate inner stresses arising during pipe-laying;

- active and passive cathodic protection against corrosion;

- a system for protecting pipelines against third-party effects, involving walking or aerial patrol;

- special measures, such as regular expansion and displacement measurements in mining subsidence areas, accompanied by action to relieve stresses within the pipeline.

Of course, provision is also made for secondary measures aimed at minimising the consequences of an incident. However, in the deterministic philosophy, such measures are not incorporated into the evaluation of the safety level to be assigned to the facility (in contrast to the probabilistic method). Secondary safety measures are merely viewed as an adjunct to primary measures.

## Optimum Allocation of Resources

To render the evaluation of high-pressure pipelines more transparent and, above all, achieve better intercomparison, Ruhrgas has together with Gaz de France and Snam developed a suitable procedure. This involved identifying the various physical parameters and factors determining the probability of occurrence of an incident and its extent. The functional interdependence of the influencing factors and the extent of damage were then analysed. This allows changes in design and operating conditions to be evaluated to ascertain whether they result in greater or lower safety. It also makes it possible to identify the sensitive points of a pipeline where available funds should preferably be invested in order to ensure a consistent safety level. This methodical approach helps to raise the overall safety of a pipeline.

The method just described achieves optimum allocation of resources and has been implemented in the form of a computer program. It permits either a deterministic or a probabilistic approach to be adopted. For example, as part of case studies, it is possible to calculate the consequences of a construction vehicle hitting a pipeline; one can also study possible incidents in terms of probability theory, starting by ascertaining the frequency of various types of pipeline damage and ending by determining the risk of injury or damage.

## Safety of Gas Supply Systems in Europe

An important question is whether the different national approaches to ensuring the integrity of gas pipeline systems based on deterministic or probabilistic methods have led to different safety standards. The answer is: no.

Statistics, such as those compiled by the European Gas Pipeline Incident Data Group (EGIG) [5], show that the average number of incidents per year and kilometre of onshore gas pipelines in various west European countries with developed gas industries is generally very low.

In these EGIG statistics, an incident is defined as an unintentional release of gas from pipelines with a maximum operating pressure over 15 bar. Incidents at gas installations and at maintenance stations are not taken into account.

Statistical data were evaluated from a total of eight companies which together operate a gas grid in the relevant pressure range with a length of over 100,000 km and can draw on experience with gas transmission exceeding 1.5 million year kilometres. Between 1970 and 1992, 0.575 incidents occurred per 1,000 km-yr. Looking at the period from 1988 to 1992, the incident rate was even well below that figure, reaching 0.381 incidents per 1,000 km-yr. Gas ignition took place in less than 3.5 % of those incidents. The main cause of unintentional gas release continues to be third-party interference. Between 1970 and 1992, there were 0.295 such incidents per 1,000 km-yr, and in the period from 1988 to 1992, the figure was 0.226 incidents per 1,000 km-yr.

There is no demonstrable link between a country's safety philosophy and the frequency of incidents. This is not surprising considering the many common features of the various European safety concepts. Regardless of the particular safety philosophy favoured, they have the following shared elements:

- binding application of a set of technical rules,
- organisational structure with clear-cut responsibilities,
- operating instructions, lists of inspection procedures, safety data sheets and rules for specific situations,
- methods and techniques for proving pipeline integrity,
- precautions against third-party impact,
- system of maintenance stations with qualified staff,
- training schedules,
- procedures for coping with incidents and emergencies,
- system for incident registration and evaluation.

As far as the details are concerned, however, there are distinct differences between the methods and techniques for achieving pipeline integrity:

- Primary and secondary safety measures have a different weighting.
- The design factors are uniform or differ if linked to a regional classification.
- Measures are based on case-by-case analyses or risk analysis.

There can be no doubt that a consistently high level of safety has been attained in developed gas industries of European countries. It is a moot point whether optimum effects as regards raising the safety level are always achieved with the funds available.

## Summary

For historical reasons, different safety philosophies have become established in the gas industry in Europe. Probabilistic safety concepts revolve around the risk posed. A risk analysis is carried out to determine the tolerable residual risk. By contrast, deterministic safety concepts as employed in the German gas industry are based on a safety analysis involving the detailed examination of possible incidents and their prevention by means of primary safety measures. Both approaches are closely linked to the respective national legal framework and cannot simply be changed. There is no link between the safety philosophy applied in a European country having a developed gas industry and the frequency of incidents in that country. The different approaches therefore rank equally in terms of the safety level reached.

As part of European integration, efforts are being made to align national regulations on the safety of high-pressure gas pipelines, for instance via a European Union directive. This would mean that European countries would have to incorporate alien elements into their national safety concepts. In turn, this would undoubtedly entail additional cost, without the proven very high level of safety ultimately being raised further. The German gas industry is therefore of the opinion that it is not necessary to standardise the legal foundations, for example in the shape of a European pipeline directive and that the tried-and-tested arrangements existing in individual European countries can be left as they are. This is in keeping with the objective enshrined in the German Energy Act of achieving energy supplies which are as secure and reasonably priced as possible.

## Literature

[1] Gesetz zur Förderung der Energiewirtschaft (Energiewirtschaftsgesetz), 13 December 1935 (Reichsgesetzblatt I p. 1451)

[2] Verordnung über Gashochdruckleitungen (GasHL-V), 17 December 1974 (Bundesgesetzblatt I p. 3591)

[3] DVGW G 463: Gasleitungen aus Stahlrohren von mehr als 16 bar Betriebsdruck - Errichtung. 1987

[4] DVGW G 466 - 1: Gasrohrnetze aus Stahlrohren mit einem Betriebsdruck von mehr als 4 bar; Instandhaltung. 1987

[5] EGIG: Gas pipeline incidents: 1970-1992. A report of the European Gas Pipeline Incident Group. Pipes & Pipelines International (1995) No. 7/8, p. 9/13