Veenker

Pipeline-Integrity-Management-System

(PIMS)

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with the following components:

Corrosion Data Maintenance (KaRoSan)

Corrosion Assessment (KaRo)

Technical Condition Assessment (TCA)

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Index

1. Summary

1.1 Preface

This paper describes methods and tools suitable for evaluating pipeline conditions based on condition monitoring and results of inspections. The result of such an evaluation can be used for managing and scheduling further maintenance activities such as inspections and surveys. Chapter 6.3.4 describes a data-management-tool for storing and organizing multiple inspection results.

This methods and tools can be used for on-land and offshore pipelines as well. The complexity of input-data and the algorithms used are freely configurable to suit the individual needs of the pipeline system in scope.

All tools described in this paper are certified by the appropriate authorities.

1.2 Pipeline-Integrity-Management-System

A Pipeline-Integrity-Management-System (**PIMS)** is a safety management system individually established for a company which aims at **no-claims and the operating safety of pipelines** including the respective equipment. Large parts of the company are subject to guarantee the integrity of the pipeline network. This involves central functions such as, for example, maintenance and also supporting functions such as purchases or staff training. The organisation and the arrangement of the individual processes have to guarantee that this aim is achieved in an economic and safe way. A minimisation of the failure rate and the consequences from failure when carrying out processes is achieved by the definition of controllable individual goals. Experience and fault analysis in the past, as well as basic legal conditions, have formed the process procedure in this direction. Furthermore, the company has to control its organisation and its chains of process to achieve the set goals. **Process integrity** is defined as complete and correct performance of the necessary processes in order to maintain integrity.

The processes of condition recognition and condition maintenance are very important in guaranteeing the integrity of pipelines. As detailed information as possible on the condition of the pipeline is helpful. All influences which could lead to failure are to be identified. The method of the technical condition assessment (TCA) is subject to determine the condition of the pipeline with aid of existing information and to asses the technical integrity.

When introducing a PIMS, in general, many processes have already been stated in other management systems, handbooks, work instructions etc. After defining the individual extent of the PIMS achievement, the relevant processes are to be defined in adherence to the legal regulations and standards and a plan of measures is to be established.

1.3 Technical condition assessment (TCA)

With aid of the TCA, an analysis of the condition and the technical integrity of a pipeline is carried out, which beyond the supervision measures, analytically comprehensibly assesses the relevant impact for every pipeline spot with the criterion of failure probability and compares it to a limit value for reliability. Limit values for the technical failure of a pressure pipeline lie in the dimension of **max. $P_f \leq 10^{-6}$** (failure with significant effect per kilometre and year) for the structural reliability analysis (SRA), i. e. the technical failure of the system. Any technical influences on the pipeline are considered in this system and are linked to one another. This probabilistic method is recognised worldwide and has meanwhile been codified in standards (e. g. ISO 16708). With this instrument, pipeline strengthening can be specifically planned for those areas in which the limit values have been reached or exceeded. With the adherence to the limit value, the technical integrity can be proven. This is especially advantageous when the requirements of the body of regulations (e. g. by metal loss) have been violated and proof of the pipeline safety becomes necessary.

The application of the TCA can be performed independently from a PIMS or as a key process in a PIMS.

1.4 Corrosion assessment with KaRo

Corrosion is, in general, the most important influence on the condition of a pressure pipeline. With the corrosion assessment KaRo both external and internal metal loss can be assessed. With knowledge of the site parameters and the medium of the pipeline, a differentiated corrosion prognosis can be carried out. On basis of the assumption a worst-case-prognosis can be established.

The procedure is, in addition to the assessment of individual distinctive features, suitable for the systematic assessment of pigging data. The application of KaRo can be effected in the framework of TCA or separately from it. The procedure is based on an extensive survey on the bearing behaviour of split pipes with metal loss by burst-tests with accompanying strain measurements and calculations according to the finite-element-method (FEM). By parameter studies and the use of neuronal networks the method was expanded in order to quickly work up single occurrences of metal loss or great amounts of data in form of feature lists of a pigging.

1.5 Data management with KaRoSan

For many pipeline system operators it has, meanwhile, become common practice to inspect the high-pressure pipelines by using intelligent pigging. Each pigging or repeated pigging results in new data packets with partially considerable amounts of data which have to be administered by the grid operator. The programme system KaRoSan makes it possible to administer pigging data and the KaRo assessment results centrally in a data base system as basis for a rehabilitation strategy. The data can be linked with other information, e. g. from the CP (Cathodic Corrosion Protection), from the GIS, consideration of company interests etc., and are kept up-to-date by determination of the measures, by corrosion prognosis and data from repeated pigging.

2. Integrity of the pipeline

Every gas company is obliged to keep its gas plant in a correct and sound condition according to safety regulations, to guarantee at any time the necessary standard of stability and supply security. These requirements aim at guaranteeing the „integrity" of the plants.

In general, it can be expected, that the pipeline condition achieves the highest quality level after construction and performance of the pressure test. This quality level is, basically, codified in the body of regulations and the quality requirements for the construction of the pipeline. This high quality level can be reduced by internal and external influences during the operation period of the pipeline. The load-bearing structure has a **useful life contingency** for the operating process to a **minimum quality standard** to be defined.

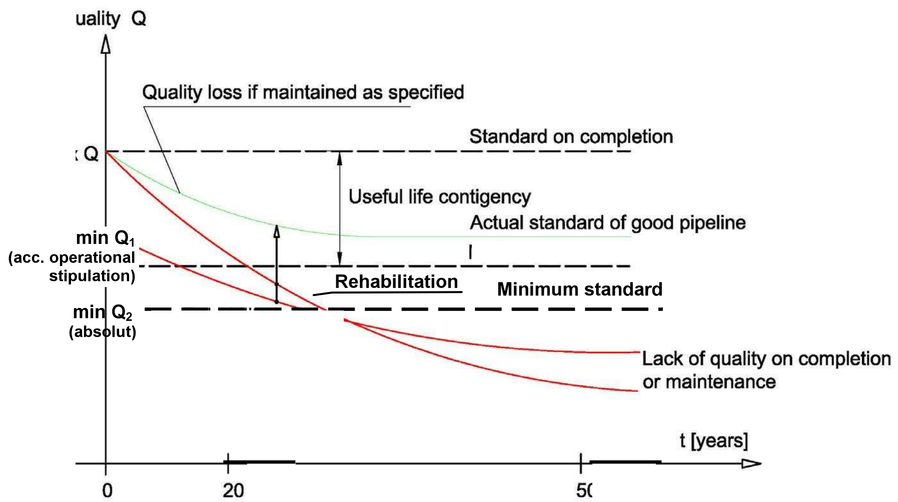

Figure 1: Reserves in bearing capacity of a high-pressure pipeline

During the course of the pipeline operation supervision measures are being carried out in order to check the due condition and to identify distinctive features in which the minimum quality might fall short or has already fallen short. The supervision measures are stipulated in the body of regulations and can be supplemented by in-house regulations.

If there is no evidence of distinctive features, then it can be assumed that the **integrity** of the pipeline is given and that the pipeline is suitable and will remain suitable for its purpose (gas or oil transportation) in adherence to the body of regulations.

The requirements of the structuring and the performance of the processes of control, supervision, maintenance and repair are of equal importance as the requirements of the technical conditions and the functioning of all components of the system. These must likewise be faultfree and of high quality.

Therefore, to maintain the holistic integrity of a pipeline, all elements of a safe operation are to be considered in addition to the technical aspects. The **integrity** of a pipeline is defined as follows:

> **Warranty of a comprehensive structural integrity and operational reliability according to specifications while yielding optimal cost effectiveness**

The pipeline has to comply with the requirements of **technical integrity** and the operation, including the maintenance, has to be performed in an economically, quality-safe, environmentally way and has to comply with the obligations. **Process integrity** guarantees that the operational environment meets the corresponding requirements of quality e. g. stipulation of tasks and competencies, training, risk consciousness, information management, documentation and communication in the company as well as with other companies and science, evaluation of success, descriptions and connections with operation processes etc.

If significant features show that the integrity according to specifications is questioned, this has to be pursued. These can be significant features in the technical field (e. g. metal loss) or significant features in the procedure process (e. g. communication deficiencies). The reaction to this information can be as follows:

1. **Need for action**

   Experience of the personnel or the body of regulations necessitate immediate action (e. g. impact of third parties with significant damage to the pipeline or unclear communication in certain special cases).

2. **No need for action**

   An impairment of the pipeline is, indeed, identifiable, but the experience of the operating personnel can safely assess it (e. g. slight displacement of a pipeline under a surface load).

If at first the situation is unclear and cannot be evaluated according to points 1 or 2, further steps are necessary to identify and assess the condition:

3. **Application of assessment procedures**

   If, on the one hand, the distinctive features found cannot be identified as not critical by the experience of the operating personnel, and, on the other hand, the taking of measures would imply economic disadvantages, it is recommended to apply recognised assessment procedures, which show the technical or operational safety or question it.

In all three cases, the integrity of the pipeline system is given again in the end. This is also the case when the results of the assessment diagnose a middle-term need for action and therefore the integrity is to be secured and to be checked in the middle term.

3. Pipeline-Integrity-Management-System (PIMS)

3.1 Overview

A **Management-System** is a modularly established form of organisation. The relevant (business-) procedures are identified and – correspondingly to defined strategies and goals (guidelines) in a system – compiled. A constant self-assessment should serve the purpose of continuous improvement.

A **PIMS** is a safety management system individually established for a company which is subject to **no-claims and safety in operation of pipelines** including the respective facilities. According to the definition, a PIMS serves the purpose of guaranteeing the safety of personnel and public as well as the protection of the environment and the guaranteeing of the reliability of transmission pipelines in consideration of the technical and economic requirements.

Thus, all processes of condition recognition and condition maintenance are involved in existing pipelines and all processes of planning and implementation are involved in newly constructed line sections. A systematic quality assurance of all operating processes as well as the assessment of incidents and emergency strategies are also components of a PIMS.

A PIMS stipulates the need for the systematic organisation and control of work procedures in regard to quality, environment, safety and economy. Thus, the company meets the legally required responsibility without neglecting economic requirements. Furthermore, management systems are suitable to regulate the information flood and to connect the manifold complex specific tasks.

The PIMS exists in addition to other management systems or organisation structures of a company, e. g. the quality management or the health and work protection, or is integrated into an ample management system regarding health, safety, environment and, if the case may be, quality (HSE(Q) MS).

In detail, a PIMS should accomplish the following:

- **Operational safety planning** with, among other things, a clearly defined programme for the operation, the maintenance and the condition supervision
    - Determination of individual goals for all levels of the organisation structure
    - A staff training plan
    - Stipulation of tasks and competencies
    - Regulations for cases of emergencies
    - Regulations for the investigation of incidents
    - Self control
- **Evaluation of the condition of the pipe** and the risk
    - Determination of the safety aspects to be supervised, constant updating and consideration of the results
    - Determination and evaluation of damage and hazards
    - Complete provision of information, information management
- Application of a **quality assurance system** for planning, construction, supervision, operation and maintenance
- Development of a system for the **performance evaluation** of the measures

As the subject „pipeline integrity" is still quite new, there is no concluding secured definition of "the" PIMS and the individual elements respectively. The publications accessible up to now by MARKOGAS, the technical specifications prCEN/TS 15173 „Gasversorgungssystem – Grundlagen für ein Leitungsintegritäts-Managementsystem (PIMS)" and prCEN/TS 15174 „Gasversorgungssysteme – Leitfäden für Sicherheitsmanagementsysteme für Erdgastransportleitungen" by CEN as well as the American regulation ASME B 31.8S, which deal with this subject, are on the one hand, very vague, and, on the other hand, differ in the definition of PIMS.

3.2 Implementation

The company firstly defines goals according to the company concept aiming at the plant security and protection of the environment, which are considered in the PIMS. The instruments and means which support the maintenance in addition to the legally required supervision measures are to be chosen as required.

In a next step a survey of the processes and the corresponding documentation is to be carried out which directly or indirectly have an impact on the safety and reliability of the pipeline. When introducing a PIMS, many processes have, generally, already been listed in other management systems, handbooks, work instructions etc. Here, integration levels and interfaces are to be determined. After determining the extent of the individual PIMS to be achieved, the relevant processes are to be defined in adherence to the legal regulations and standards, and a plan of measures is to be established. This comprises among other things:

- Documentation guidelines
- Compilation of a management handbook with process instructions
- Training and information of the staff
- Determination of correction measures for continuous improvement
- Internal and, as the case may be, external audit

The determination and documentation of processes and work procedures in a handbook guarantee that these are performed systematically, are controllable and can be corrected by control of success. Both the degree of the implementation and the success of the PIMS are to be assessed, and the results are to be considered correspondingly in the further procedure.

4. Guarantee of process integrity

If a company applies a well planned PIMS, the conditions for the guaranteeing of the **process integrity** are already given. **Process integrity** is defined as complete and correct performance of the processes necessary for the maintaining of integrity.

In a company, a multitude of activities are carried out in order to achieve the defined goals with economic success and in consideration of the legal conditions. The activities are organised in business processes and in work procedures. Modern business management concentrates on the business processes as basis of the structuring of the company organisation. Many processes result from grown structures and are constantly influenced by multitudinous conditions which constantly change (e. g. Law on the Use of Energy, Hours of Work Act, technical developments such as information management, GIS etc., economics). Thus, there is no universal solution, but a multitude of complex organisation part structures, which in dependence on one another, achieve the goal.

Large parts of the company are involved in guaranteeing the **integrity** of the line network. These comprise central functions such as the maintenance and supporting functions such as e. g. purchase or staff training. The organisation and the composition of the individual processes have to guarantee the economical and secure achievement of this goal. A minimisation of the failure rate and failure consequences when carrying out processes is achieved by the definition of controllable individual goals. Experience and failure analysis in the past as well as the general legal conditions have had an impact on the work procedure. Furthermore, the company has to check its organisation and its process chains in view of the achievement of goals. If irregularities or incidents occur, these are to be pursued as part of the organisation.

The correct performance of the processes (trained staff, communication structures, information management etc.) guarantees the **process integrity**, which serves the maintenance of the integrity. Suitable measures, such as the establishment of guidelines and control of success, e.g. audits, have been listed in chapter 3.2.

5. Proof of technical integrity

When introducing a successful PIMS, the identification and evaluation of damage and hazards as well as the assessment of the pipeline condition and the provision of the relevant information are indispensable. An analysis of the pipeline condition becomes necessary, when, as described in chapter 1, information on distinctive features of a pipeline is known which is subject to a more detailed assessment in order to rule out an impairment of the integrity.

The **technical integrity** can be proven by methods which are able to assess technical systems in regard to their integrity, even if the requirements of the body of regulations have been violated. A number of instruments are available to the operator, which are able to find distinctive features (e. g. intelligent pigging, CP-measuring, inspections etc.) and to assess them (e. g. by TCA). It occurs that as a result of an assessment the technical integrity can be proven, on the one hand, but that in the middle term in view of provision and guaranteed future strengthening is shown.

The period of validity basically existing for the integrity proof due to the changeability of the pipe condition is, in this case, limited. Correspondingly, the strengthening measures are included in a maintenance plan. If the period elapses without implementation of the planned measure, the integrity proof is not valid any more and a new assessment of the present condition becomes necessary. Thus, it is wise to consider and to pursue the process of implementation of the strengthening measures stated in the condition assessment including its documentation and control of success as part of the actual **technical integrity proof**. If this process is successfully determined and pursued, the integrity of the pipelines which are in this process, can be considered as proven.

The central process of the aforementioned technical integrity proof is shown in figure 2:

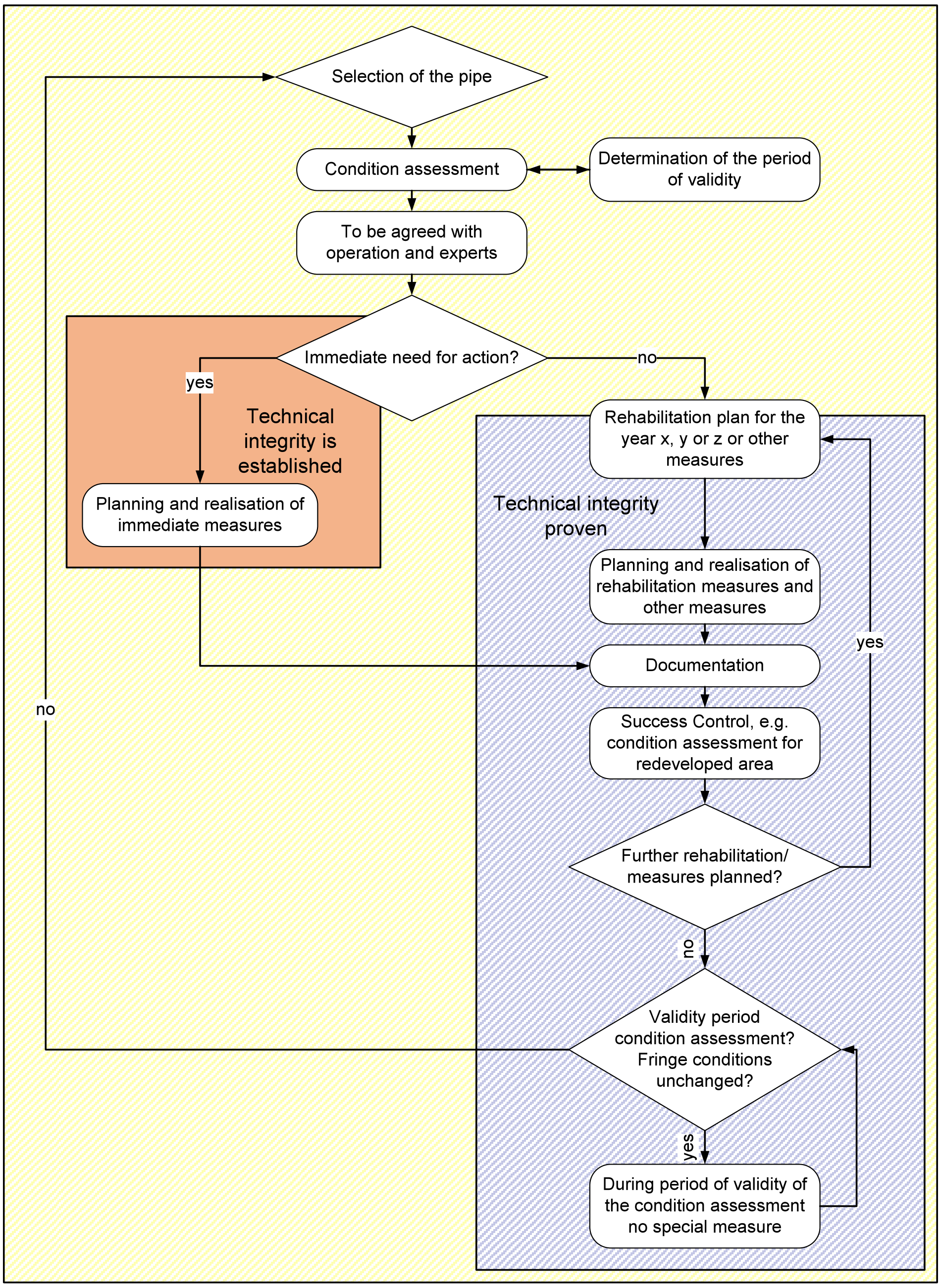

Figure 2: Process technical integrity proof

In regard to a forward-looking maintenance strategy preferably ample knowledge on the technical pipeline condition form the quintessence of the process of maintenance and gurarantееing of safety and reliability of transmission pipelines. The application of instruments of the condition assessment can, in the framework of the maintenance planning, be systemised and automated, in order to control rehabilitation and inspection work and to apply them effectively. It can be an advantage for the company to do without a complete PIMS at first and to focus on the condition assessment of individual pipes or the whole pipeline network, in order to e. g. advance the rehabilitation control in the short run or to find critical points at an early stage when constructing new pipelines.

6. Technical condition assessment (TCA)

6.1 Overview

The condition of the pipeline has to be described by a method that can be uniformly applicable to all descriptive data of the condition. Furthermore, the method should be able to link the data in a technically correct way (e. g. corrosion on a deformed pipeline) and the results have to be comparable to one (or more) **limit value(s)**.

A system that meets this requirement reasonably and completely, is the operating with the criterion of **failure probability.** This probabilistic method has worldwide recognition and has, meanwhile, also been stipulated in standards (e. g. ISO 16708). Figure 3 shows that for every impact the individual failure probability Pf is identified and that this individual failure probability is then linked to a total failure probability for every individual pipe spot. It is possible to standardize all impact including the damage statistics to this failure probability quite smoothly and, thus, to compare it to the same limit value as the other parameters.

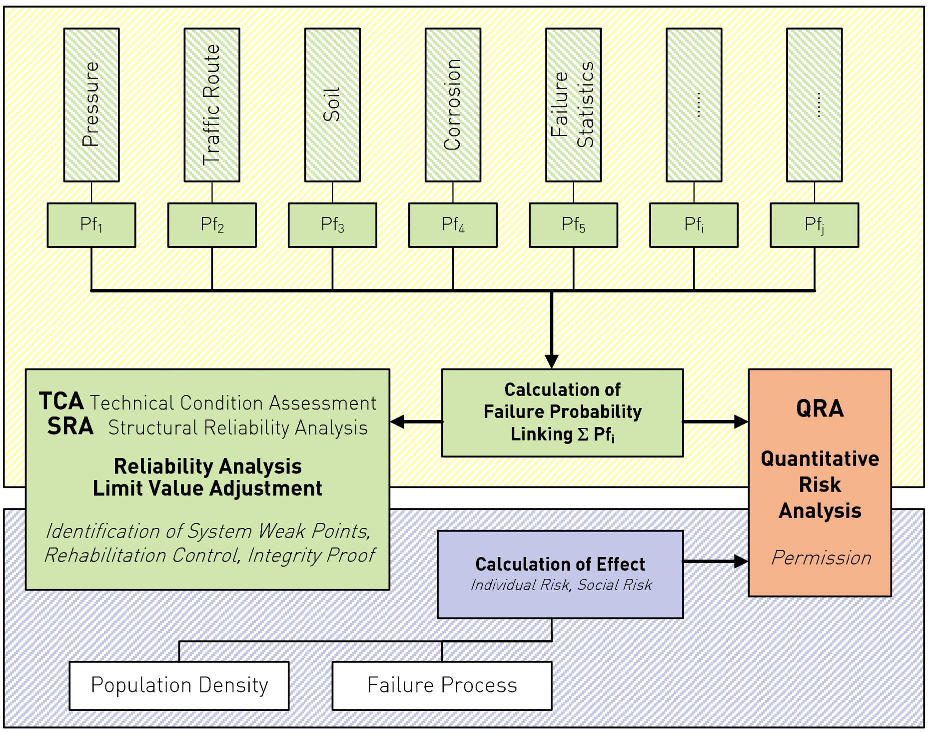

Figure 3: Failure probability, QRA and SRA

Limit values for the technical failure of a pressure pipeline lie in the dimension of **max. Pf $\leq 10^{-6}$** (failure with significant effects per kilometre and year) for the structural reliability analysis (SRA) i.e. the technical failure of the system. This limit value corresponds to min Q_1 from Figure 1 and thus, represents the lower limit of the useful life contingency. If the limit value is exceeded, this pipeline section is incorporated into a plan to carry out measures and the respective parameters are shown. These measures can either be immediate measures or a rehabilitation plan (figure 2). A rehabilitation plan with a corresponding time-dilation is only acceptable, if the failure probability is lower than stipulated by min Q_2 (Figure 1). For this value there are no standards and in literature there are only limitations to min Pf $< 10^{-2}$. This value should be determined in consideration of the individual cases and, as the case may be, after consultation with the supervisory authorities.

With the **Technical Condition Assessment** a separate analysis of the condition and the technical integrity of a pipeline is carried out, which beyond the supervision measures, analytically and comprehensibly assesses the relevant impact for every pipeline spot with the criterion of failure probability and compares it to a limit value for reliability. Any technical influences on the pipeline are considered in this system and are linked to one another. By means of this instrument strengthenings can specifically be planned for those areas in which limit values are reached or exceeded. In adherence to this limit value the technical integrity is proven by the SRA. This is particularly advantageous, when the requirements of the body of regulations (e. g. by metal loss) have been violated or proof of the "pipeline safety" becomes necessary.

The system is structured modularly. From a pressure stage of about 4 bar upwards the pressure capacity of a pipeline plays a dominant role and the resulting pipeline assessment is combined with the assessments resulting from other influences. The modules are, of course, constructed in variable fashion, so that, for example, different corrosion effects and processes can easily be incorporated or further influences can be added. Expert data can also be adopted into the system, which, for example, describes the interaction between pipe and soil.

The forecasting models, which show developments over time, are based on different principles. On the one hand, physical/technical knowledge is incorporated, for example the principally familiar corrosion models, and, on the other hand, knowledge-based models are used which determine the progression of the quality level in the course of time by way of ageing processes, frequency of third party impacts etc.

The performance of the TCA leads to results which show a constant failure probability for every pipe section, in which all data is constant. The failure probability changes at every section limit. The sections can be very short (e. g. the influence area of a corrosion spot) or show great lengths, if the standard cross-section is constant and no particularities are documented. A result is shown in figure 4. This is the typical case that the standard cross-section of a high-pressure pipeline has a failure probability in the dimension of 10^{-15}. Many distinctive features lead to peaks, which, however, do not exceed the limit value for the SRA of 10^{-6} and thus, are not subject to further consideration. Only a few distinctive features necessitate direct measures which, in general, cannot be delayed.

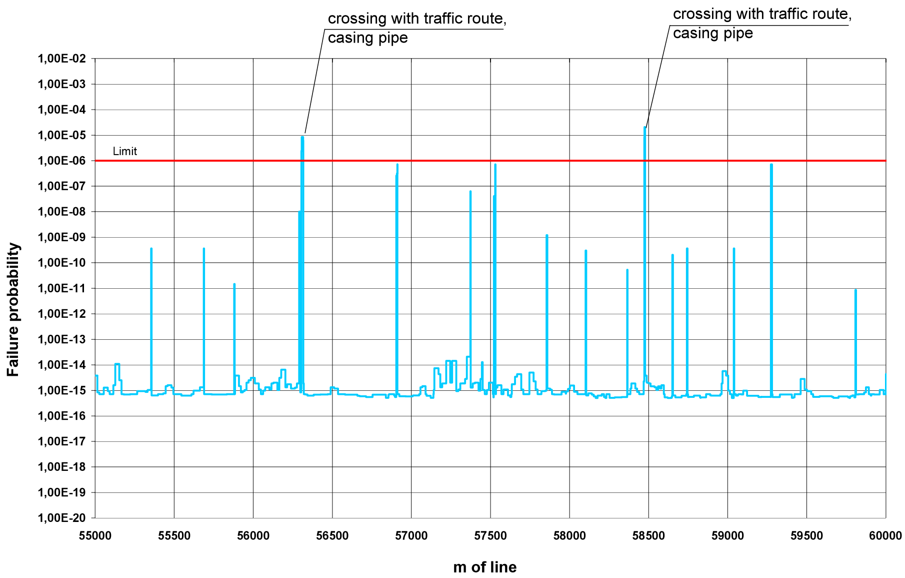

Figure 4: Results of the technical condition assessment (TCA)

By parameter studies – in particular the **ageing** of the pipeline in the system – the influences are identified which can become critical in future.

From these prognoses the period of validity for the result can be derived. In general, periods of about 10 years are aimed at. As changes in the respective basic data discard the result of the condition assessment performed, it is to be guaranteed in this phase that the corresponding processes are induced.

6.2 Evaluation of condition by QRA

With the quantitative risk analysis (QRA) the risk is formed as a product of the failure probability (occurrence probability of significant damage) and the possible effects of this damage. The effects – e .g. the consequences of the diffusion of a gas cloud – are investigated with the aid of incident scenarios. The failure probability can be determined with the TCA. The individual or geographical risk in the pipeline area is described by outlines. Figure 5 shows how the risk varies for a single person with distance to the pipeline alignment.

Figure 5: 10^{-8} (yellow) and 10^{-7} (red) outline in pipeline area (white)

From this illustration, the social risk can, furthermore, be determined, if these outlines are compared to the site density or the humans regularly staying in this area.

The individual and social risks are evaluated on the basis of the social consensus analogue ISO 16708. Alternatively to the SRA, thus, a limit value for the failure probability can be derived from the QRA, which considers e.g. the density of population in the pipeline area.

6.3 Corrosion in the TCA

6.3.1 Overview

Corrosion is, in general, the most important influence on the condition of a pressure pipeline. For the consideration of corrosion as far as the condition assessment by the TCA is concerned, two methods are available. The selection of the suitable method depends on the pigging possibilities of the pipeline.

If the pipeline is not piggable, the TCA offers a calibrable corrosion model based on some pipe parameters, which can be applied without knowledge of the actual pipeline as far as corrosion is concerned (cf. chapter 6.3.2). The relevant corrosion influences are compiled and evaluated in combination. Annual rates of loss are related to the pipeline and the results are accumulated in consideration of the changing history. The failure probability is identified as result of the TCA application for the potential metal loss.

If the pigging possibility of the pipeline is known, and the pigging data is available, the strongly differentiating system „KaRo" can be applied (cf. chapter 6.3.3) which can determine very exactly with the aid of a few parameters the strain to the geometry of metal loss and to the pipe. The admissibility of the metal loss results in consideration of all further influences on the failure probability as a result of the condition assessment by the TCA.

6.3.2 Corrosion assessment without pigging data

For the assessment of not piggable or at present not yet pigged pipelines the condition assessment contains a corrosion model which on the basis of data on the age of the pipeline, the coating, the soil aggressiveness, the condition of the CP as well as, as the case may be, other existing influences calculates the potential metal loss and considers it in the assessment.

Such a corrosion model can be adjusted to the local particularities of the pipeline site. In the most simple case it works with linear rates of loss, the dimensions of which are influenced by the influence parameters. The punctual verification of the results, e. g. by uncovering, is recommendable.

6.3.3 KaRo

When working on piggable pipelines with the condition assessment, a procedure is necessary, with the aid of which the results of the pigging are available to the condition assessment and can be further operated with. This is provided by the programme system „KaRo“.

The corrosion assessment „KaRo“ is applicable to pressure steel pipes. Internal and external metal loss can be assessed. With knowledge of the site parameters of the pipeline, a differentiated corrosion prognosis can be carried out. On the basis of assumption, a worst-case-prognosis can be performed.

KaRo can be applied for metal losses meeting the following boundary conditions:

- Pipe parameters
  - Materials with yield strengths of Re = 190 N/mm² to 485 N/mm²
  - Outside diameters of 100 mm to 1440 mm
  - Nominal wall thicknesses between 3 mm and 40 mm
  - Ratio wall thickness to outside diameter up to 0.05

- Metal loss parameters
  - Corrosion depths up to 90 %
  - Minimum remaining wall thicknesses up to 1.0 mm
  - Circumferential expansions up to ½ pipe circumference
  - Ratio longitudinal expansion to circumferential expansion up to 8.0
  - Ratio longitudinal expansion to square root of the product of pipe radius and nominal wall thickness up to 20.0

$$\left(\frac{Lx}{\sqrt{Da/2 \cdot t}} \leq 20.0\right)$$

As a rule, these limits cover all cases appearing in practice. If they should still be broken for single metal losses, they can be assessed manually.

Basis

In the course of burst-tests with accompanying strain measurements and calculations according to the finite-element-method (FEM) the bearing behaviour of split pipes with metal loss was investigated.

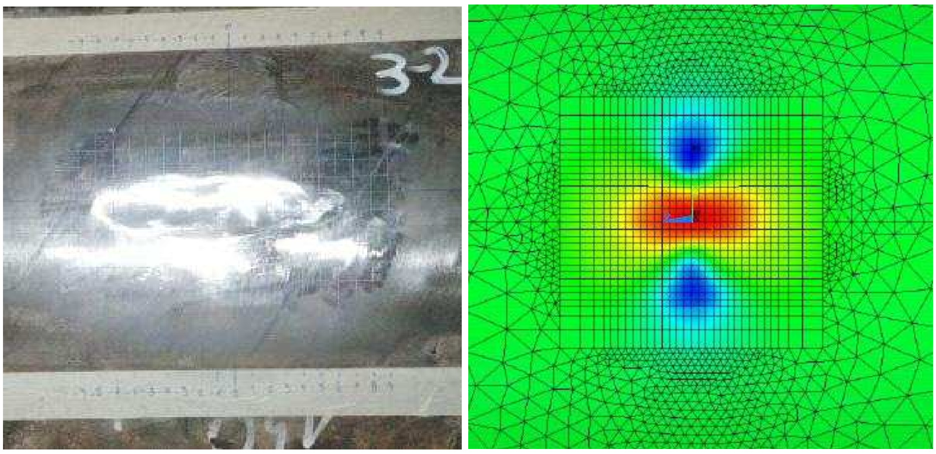

Figure 6: Metal loss and FEM result

The FEM is a numerical calculation method in widespread use in engineering which is based on principles of continuum mechanics and permits a sufficiently exact representation of any structure in an engineering model. This procedure makes it possible to consider exact error geometry and allows the interaction of several damage and load conditions (internal pressure and additional loads). By means of parameter studies and the use of neuronal networks the method was extended in order to be able to process both individual occurrences of metal loss and large quantities of data quickly. This design procedure is implemented in the KaRo programme system.

KaRo has the advantage that an assessment is possible on the basis of few parameters, which indicate the metal loss geometry and the pipe parameters. This applies both to individual metal loss and to complete pigging results.

6.3.4 KaRoSan

For many pipeline system operators it is, meanwhile, common practice to inspect the high-pressure network with the use of intelligent pigging. The piggings are carried out separately for the pipe sections, as the case may be, in partial sections. Each pigging or repeated pigging results in new data packets with partially considerable amounts of data, which have to be administered by the grid operator. Here the programme system KaRoSan is applied. The programme makes it possible to administer and update the KaRo assessment results on basis of pigging inspections in a database system as basis of a rehabilitation strategy.

In the course of the rehabilitation planning it is necessary to link the pigging data with further information such as e.g. from the CP, the GIS, consideration of company interests etc. The programme system supports the operator with the recording of this data and makes it possible to record data by means of interfaces from other sources such as GIS. Furthermore, „KaRoSan“ provides support with the specific performance of differentiated assessment steps in the corrosion prognosis e. g. with the application of exact finite element calculations of critical corrosion spots.

KaRoSan supports the pipeline system operator with operational processes in the rehabilitation of critical pipeline characteristics on the basis of pigging data with local and temporal planning of the rehabilitation measures, with the recording of the actually performed rehabilitation measures for the updating of the data base as well as the control of repeated pigging operations.

7. Areas of application of the condition assessment

The TCA is, due to its modular composition in its basic structure, applicable to different questions which are shown as an example in the following:

Planning and construction

In adherence to the requirements of construction and planning defined in the body of regulations, data is filed according to the documentation input e. g. of a PIMS. In the planning phase a condition assessment can already be carried out for the intended pipe parameters and the constructive design. By this, unfavourable combinations of environmental influences and pipe stress can be identified in the forefront and can be mitigated by corresponding measures (section-wise increased wall thickness, setting up of additional marking posts at significant points, carrying out of specific soil investigations etc.).

Authorisation

When establishing a risk analysis, a SRA or QRA according to the European body of regulations, this analysis can support the authorisation process with the German regulating authorities, in particular for the transport of inflammable or toxic media, which have been transported on the road up to now. The calculation of the failure probabilities carried out in the TCA and the comparison to a limit value already presents a SRA. If the effects of a damage are described in scenarios and are incorporated into the assessment by multiplication with the TCA results, then the individual risk and the social risk have been determined quantifiably and assessable in a QRA. By the applicable limit values the admissibility or efficiency of a planned measure can directly be shown.

Documentation and integrity proof

In a relatively new high-pressure pipeline grid with few distinctive features the application of the TCA will, at first, be limited to the documentation of the events (e. g. corrosion spots found, new crossings with traffic routes, repairs made etc.). With increasing age of the grid, these influences will become more numerous. With the application of the condition assessment it can be shown whether the technical pipeline integrity is still given or the combination of several influences already exceeds the limit value.

Pipelines can apparently, for various reasons, be contrary to the body of regulations partially or totally. This can be expressed e. g. by falling below the mimimum coverage or can be due to significant additional loading (e. g. crossings with extensive traffic routes) or the transport of special fluids, which are not explicitly contained in the body of regulations. In all these cases, the pipeline leaves the area complying with the rules, but it cannot be ruled out that the integrity proof can, nevertheless, be provided.

By this means operational strategies can be specifically optimized under the aspects of safety and economy.

Rehabilitation measures

In older high-pressure pipeline grids in need of repair or rehabilitation, the TCA, if consequently applied, will show the following positive effects:

- Separation of line sections in need of rehabilitation from sections the required stability of which is not questioned in spite of distinctive features
- Priorisation of necessary measures
- Secure budgeting for the measures to be carried out
- Identification of the remaining time of use to the possible loss of the technical integrity, especially in the case of metal loss
- Repeated use of inspection measures (e. g. intelligent pigging) instead of rehabilitation
- Acceptance of these decisions by the supervisory authorities.

By this means, unstructured rehabilitation concepts can be optimized and can be arranged in a chronologically correct way.

8. Terms and Definitions

Term	Definition/Comment
Integrity	Warranty of a comprehensive structural integrity and operational reliability according to specifications while yielding optimal cost effectiveness. The **integrity** of a pipeline comprises the **technical integrity** and the **process integrity.** (Cf. chapter 1)
Technical integrity	Technically safe condition of a system. (Cf. chapter 1 and 5)
Technical integrity proof	Is proven by methods which are able to assess technical systems regarding their **integrity**, even if requirements of the body of regulations have been violated. The process of the implementation of the strengthening measures shown in the condition assessment including its documentation and control of success is considered and pursued as part of the technical integrity proof. (Cf. chapter 5)
Process integrity	Complete and correct performance of the processes necessary for the maintenance of integrity. Guaranteeing of the **process integrity** is given by the corresponding organisation structure, definition and supervision of controllable individual goals, failure analysis and constant improvement of the procedures. (Cf. chapter 4)
PIMS **Pipeline-Integrity-Management-System**	A **PIMS** is a safety management system individually established for a company which is subject to **no-claims and safety in operation of pipelines** including the respective facilities. A PIMS serves the purpose of guaranteeing the process of process integrity and technical integrity. (Cf. chapter 3)

Veenker

Technical condition assessment (TCA)	Analytical method of the technical condition assessment and the proof of technical integrity of pipelines which is used for rehabilitation control. The relevant influences for every pipeline spot are comprehensibly assessed by the criterion of failure probability and compared to a limit value for reliability. (Cf. chapter 6)
SRA	Stuctural Reliability Analysis Is used with the application of the TCA to proof the **technical integrity**. (Cf. chapter 6.1)
QRA	Quantitative risk analysis. The risk is formed as product of the failure probability of significant damage and the possible effects of this damage. The effects – e. g. the consequences of the diffusion of a gas cloud – are investigated with the aid of incident scenarios. The **QRA** can be used as proof of **technical integrity** with the application of the **TCA.** (Cf. chapter 6.2)
KaRo	Programme system for the systematic assessment of metal loss and pigging results. (Cf. chapter 6.3.3)
KaRoSan	Programme for the central administration and updating of **KaRo** assessment results on the basis of pigging inspections in a database system for rehabilitation control. (Cf. chapter 6.3.4)

9. References

The following list of references shows that pipeline integrity analyses covering different aspects and individual interests of well-known pipeline system operators have been carried out. In all cases the task was to make economic optimizations without the intended safety of the pressure line being compromised.

Year	Operator	Characteristics
1989-95	BEB	Network evaluation
1992	FSG	Evaluation of low pressure network
1994	VNG	Network evaluation
1999	EVG	Network evaluation
1999	VNG	Threshold criteria
2000	Ruhrgas	Threshold criteria
2000	Avacon	Threshold criteria
2002+08	WINGAS	Feasibility study
2002+05	Gas-Union	Proof of integrity
2002	Thyssengas	Threshold criteria
2002	DVGW / RG	Optimisation of monitoring periods
2002	PLE	Evaluation of fittings / stations
2002+04	IVG	Proof of integrity / flow lines
2002	SpreeGas	Threshold criteria
2003	GASAG	Threshold criteria
2003	DVGW	Optimisation of monitoring periods
2003	DVGW	Risk of wind turbines
2003-04	EPDC	Synthesis gas pipeline, QRA
2003	BOC	Quantitative Risk Analysis
2004	VNG	PIMS; cost structure analysis
2004-08	VNG	Application of PIMS
2004	Degussa	Proof of integrity
2004	EVG	Evaluation of insufficient cover
2005-08	EVN	Proof of integrity
2005	VNG	Data management KaRoSan
2005	RWE	Proof of integrity
2005	FBG	Oil transmission pipeline
2006	EWE	Network evaluation
2006	Linde	Assessment of oxygen pipeline

Year	Operator	Characteristics
2007	SCOT	Rehabilitation of oil pipeline
2007	Wintershall	Assessment of metal loss after pigging
2007-08	VNG	Assessment of metal loss after pigging
2007-08	VNG	Quantitative Risk Analysis
2007	Various	QRA of wind power plants
2007	Stadt Duisburg	QRA of CO-Pipeline
2007	Gas-Union	Assessment of metal loss after pigging
2008	NWKG	Proof of integrity
2008	iro	Assessment of CO-Pipeline
2008	NWKG	Assessment of „dent caused by excavator“
2008	VNG	Proof of integrity
2008	Geomagic	KaRo integration