A COMMON APPROACH FOR ASSESSING THE SAFETY OF NATURAL GAS COMPRESSOR STATIONS

Main author
Karine Kutrowski, N.V. Nederlandse Gasunie, Groningen, The Netherlands

Co-authors
Eric Jager & Robert Kuik, N.V. Nederlandse Gasunie, Groningen, The Netherlands
Alessandro Cappanera, Marilena Negretti, Andrea Castellaneta & Roberto Ferraris, SNAM Rete Gas S.p.A, San Donato Milanese, Italy
Emmanuel Freitag, Cyrille Fleury, Malika Madouï–Barmasse & Sandrine Cervoni, Gaz de France, Paris, France
ABSTRACT

In 1997 four European gas transmission system operators, Gaz de France (F), N.V. Nederlandse Gasunie (NL), E.-ON Ruhrgas (D) and SNAM Rete Gas S.p.A. (I), took the initiative to work together in order to share and improve their knowledge of natural gas compressor stations. This cooperation was formalised by setting up the WGCS (Working Group on Compressor Safety). The WGCS has been working on the development of a common methodology for assessing the safety of natural gas compressor stations. This methodology is being implemented in a software called SARONG (Software for the Assessment of Risk On Natural Gas stations).

SARONG is a system developed by Tessella Support Services plc. on behalf of the WGCS. By developing SARONG, the WGCS strives to achieve one main objective: the development of a common approach for providing a fast and accurate assessment of the overall safety level of gas compressor stations.

The key features of the common methodology are:

- Modelling the key components of compressor stations and their properties
- Representing the adverse events which can occur using the method of Fault Tree Analysis
- Calculating the physical consequences of unwanted events
- Combining the frequency of events with their effects to evaluate the system safety
- Providing an easy to use and powerful analysis tool

This common methodology, in line with the different needs of the WGCS companies, should allow the risk analyst to:

- Produce a quantitative safety assessment to be used in safety reports
- Demonstrate clearly the calculated safety levels to regulatory authorities
- Optimise safety aspects from a design, maintenance and operational point of view
- Get a relative ranking of the safety level of several compressor stations in order to find the weakest spots
- Give an idea of sensitivity of components in relation to the overall safety of the plant
- Investigate the influence of different design criteria for the same component

This paper introduces the WGCS and describes the common methodology developed for assessing the safety of natural gas compressor stations.
TABLE OF CONTENTS

Abstract

Introduction

1. The WGCS

2. The common methodology

3. SARONG

Conclusion

Acknowledgements

References
INTRODUCTION

Gas transmission system operators build compressor stations along their pipelines, typically one every 100 kilometres. The size and the number of compressors vary, based on the diameter of the pipe and the volume of gas to be moved. The companies operate the natural gas compressor stations in accordance with all applicable safety standards established by the authorities. Although the number of accidents is low, the transmission system operators always strive to improve the safety conditions of their compressor stations and to follow operating practices that will safeguard employees, contractors, third parties and environment.

For this reason, in 1997 Gaz de France, N.V. Nederlandse Gasunie, E.-ON Ruhrgas and SNAM Rete Gas S.p.A. set up the WGCS and have since then been working on a research project to analyse major safety issues of these installations [1].

This paper first introduces the work done by the four gas transmission system operators within the WGCS. The second chapter describes the common methodology developed by the companies for assessing the safety of natural gas compressor stations and explains the links between incident scenarios, consequence evaluation and safety studies. Finally the interface of the prototype software SARONG in which the methodology is being implemented is shown and some examples are given.

1. THE WGCS

For almost 10 years, the WGCS has encouraged a technical collaboration between the above mentioned companies. The activities of this group were divided into two phases: firstly the development of the methodology and secondly its implementation in a software for computer-aided analysis of gas compressor stations.

The main outcome of the first working phase is a methodology manual for the safety analysis and assessment of gas compressor stations. For this purpose, the WGCS members from research, technical and operational departments shared their experience and knowledge. The resulting methodology is explained in more detail in chapter 2.

The second phase is based on the same principles as the first phase: research, technical and operational departments have been involved in plenary committee meetings for information exchanges and in common activities for knowledge sharing. The main result of this phase is the development of the prototype software SARONG for the computer-aided safety analysis of compressor stations.

SARONG is a software which helps and guides the safety analyst to manage the great amount of information that is essential for performing the complex procedures of the common safety assessment methodology. Some examples of implementation of the methodology in the prototype software SARONG are given in chapter 3.
2. THE COMMON METHODOLOGY

By developing a common methodology the group has strived to standardize the necessary steps of a safety study so that they would fulfill the specific purposes and needs of each participating company. The idea was to list in a common way all the potential hazards of such an installation, to assess their consequences and likelihood and to evaluate the safety level around the station. To ensure the methodology would be useful to all four companies, the group has also taken into account all the mandatory differences and specific requirements by local authorities. As a result the common methodology has been developed and consists of a set of procedures. The main steps are the following:

- Identification and description of all components and systems of a typical compressor station.
- Characterization of all the hazards embedded in the compressor station systems by means of detailed hazard analyses such as HAZOP (Hazard Operability study).
- Modelling of all the undesired events identified by the hazard analyses. All these events are analysed in a top-down approach into basic events with FTA (Fault Tree Analysis) techniques.
- Detailed assessment of failure rates for all the basic events. DNV (Det Norske Veritas) produced a reliability assessment for components and systems, including human-related adverse events probabilities.
- Estimation of the undesired events frequencies. Once the fault trees are completed and the failure rates of all basic events are known, it is possible to evaluate the failure frequency of each undesired event.
- Calculation of the undesired events consequences. Explosion, fires and effects on people in the area are analysed.
- Overall safety assessment of the system for the station and the surrounding area.
- Suggestions for safety improvement strategies.

The description of a typical compressor station common to all four companies, the use of FTA technique, the calculations of consequences and effects and the safety assessment of the station are described in more details in the following paragraphs.

2.1 Description of a “typical compressor station”

The first step was to define a common terminology in order to have a unique and clear definition of the kind of installation to be studied. The typical installation considered is an onshore transmission natural gas compressor station and is mainly composed of:

- One or more compressor units
- Pipelines
- Gas service piping (including filters and coolers)
- Control and safety devices
- Station auxiliary equipment and facilities

In order to have a more complete identification of a typical compressor station, a matrix description of the compressor station components with the relevant links, plausible failures, possible consequences and installed safety and protection systems has been produced. A specific numbering system has also been applied to all equipments so that they are easily identifiable throughout the project, i.e. in the
fault trees, database and software. In this common definition all information about design, operational criteria and preventive safety measures applied by each company was used.

2.2 FTA technique

The second step was to identify the undesired scenarios and potential hazards. These were determined on the basis of the results of the matrix descriptions analysis, experience of associated companies, the historical data collection and the application of hazard identification techniques.

Subsequently the FTA technique has been used to build an integrated fault tree, called the compressor station fault tree, to identify the incidents and to obtain the causal chain that allows estimating the probabilities through a qualitative failure analysis. The compressor station fault tree has been carried out including the following seven undesired events (also called top events):

- Explosion in enclosure
- Explosion in hall
- Explosion in gas path
- Fire in enclosure
- Fire in hall
- Fire outside hall
- Fire at vent stack

The compressor station fault tree consists of 200 basic events that lead to an undesired event and the causal chain of the selected incidents. Figure 1 gives an example of one of the 50 branches of this fault tree.

![Part of the compressor station fault tree](image)

*Figure 1* Part of the compressor station fault tree
In addition to the FTA a dedicated reliability database has been developed with support from DNV [2], [3], [4] to assess the frequencies and probabilities of the basic events involved in the compressor station fault tree.

All the failure modes of the equipment of the typical compressor station have been considered [5], [6]. The reliability database is composed of several types of data:

- **Leak frequency data**: the leak frequency is expressed in a formula, depending on the diameter and the leak equivalent diameter, for piping, valves and flanges. For equipment such as filters, pumps and heat exchangers the data mainly come from offshore equipment databases.
- **Safety systems failure data**: the PDS (Norwegian acronym for reliability of computer based safety systems) method is used to quantify failure probabilities for safety systems.
- **Ignition probabilities**: ignition probabilities are estimated using an ignition model developed for offshore QRA that describes ignition probabilities for releases within offshore modules as a function of time. The ignition probability modelling is divided into three main parts: dispersion modelling, ignition sources, and the ignition probability model. The final result is an ignition probability value that depends on the outflow rate of the flammable/explosive fluid.
- **Human failure probabilities**: estimation of human failure probabilities has been based on the TESEO (Tecnica Empirica Stima Errori Operatori) method [7]. The human failure probability is defined as the probability that an operator does not complete a job successfully when requested by the system, within a certain maximum time limit permitted by the system.
- **Rare event**: estimation of rare events, the estimation of frequencies or probabilities in situations where the available information is scarce, is treated by standard Bayesian technique.

All the collected data form the basis for the calculation of failure frequencies of basic events and, using the fault tree, of top event probabilities. According to in-field experience, all the reliability data are constantly analysed and tailored to real compressor stations.

### 2.3 Consequences calculations

The consequences were expressed in terms of severity of the damage on people and structures both based on threshold of the physical effects. The first objective was to list the physical phenomena to be studied and to give theoretical models to simulate them. It led to indications on software models available among the companies that could be used for performing consequence calculations of the identified undesired events.

Therefore, it was necessary to implement modules for leak size dependent transient mass flow rate calculation, calculation of LEL (Lowest Explosive Limit) shape or spill area, flame length estimation, calculation of time-dependent heat field, conversion of thermal radiation into dosage fields and assessment of thermal threat [8], [9].
As a result of the research mentioned above, the developed methodology, in terms of consequences, allows the calculation of the:

- Mass flow: using methods and models for estimations of the characteristics of releases.
- Heat radiation and flux: based on the outflow and the related emissive power.
- Effective heat dose: calculated as the received heat flux in time.
- Lethality: using the probit function and the coefficients of Eisenberg or Lees.

### 2.4 Safety studies

Finally after combining the results of the FTA, of the probability and frequency assessment and of the consequences calculations, the methodology allows the analyst to perform a complete safety study by:

- Giving failure frequency of components and systems, including human error probabilities and adverse conditions;
- Simplifying the management of fault trees for description and evaluation of undesired events;
- Calculating consequences and effects for all the selected incident scenarios, including fire and explosion events;
- Calculating the most common safety indicators (e.g. individual, inhabitant and societal risk) to be included in safety studies;
- Investigating the influence of different design criteria and support designers in selecting and analysing protective measures
- Allowing the ranking of different compressor stations or equipments (e.g. for scheduling maintenance).

Safety studies are based on standard indicators; the methodology allows to obtain information about the safety level connected to the considered activities inside and outside the compressor station area. Some of these standard indicators can be:

- The individual risk, also known as location specific risk, is presented as contour lines or iso-curves on a topographic map.
- The inhabitant risk, also presented as contour lines or iso-curves on a topographic map.
- The societal risk, presented as an FN curve.
- The expected number of casualties.

### 3. SARONG

As the working group and the common methodology have been presented in the previous chapters, this chapter introduces the prototype software SARONG and gives some examples of the methodology being implemented.
3.1 SARONG interface

SARONG is a stand-alone application for Windows for use in a typical office environment. Its MDI (Multiple Documents Interface) is customary for users experienced in using Microsoft Office products. The toolbar is displayed in Figure 2 and the icons along with the menus and their options can be used to start the functions desired.

![SARONG toolbar](image)

**Figure 2 SARONG toolbar**

One of the key features of the common methodology is the modelling of the key components of the compressor station to be studied and their properties. This modelling is done on the station plan that is part of the station design window. Figure 3 shows the station design window.

![SARONG station design window](image)

**Figure 3 SARONG station design window**

The left main frame consists of the component hierarchy (or tree), which contains all the components in the station. It is sorted by type and in a parent-child hierarchy. The large frame on the right in the left figure is the station plan, which shows a graphical overview of the station, along with all the components that have been placed in it. By creating a component the user must fill in its properties as they are displayed on the right window of Figure 3. By repeating the procedure of creating components we obtain a diagram as the one shown in Figure 4.
3.2 Examples of implementation of the methodology

The essence of the common methodology is not only based on modelling the components of the station but also on using the FTA technique, calculating the physical consequences of events (such as explosions and fires) and, when combining the frequency of these events, evaluating the safety of the station.

As explained in chapter 2, a number of top events related to the main types of undesired occurrence in the station have been pre-defined. Each top event is made up of a tree structure known as a fault tree, which combines basic events. Each basic event has a formula or algorithm to calculate either the probability of occurrence, or the failure frequency (events per year).

The graphical presentation of the pre-defined fault trees and their basic events in SARONG is shown in Figure 5.
The frame on the left shows the fault tree hierarchy with the seven pre-defined fault trees, whereas the right frame shows a graphical view of a part of a tree after one is selected in the hierarchy. This part of the tree, for example, shows that for a fire due to gas release from PSV valves to occur, three events must take place: a PSV valve must release gas, there must be a gas ignition source present and the flame detection system must fail. In this example the "Leakage from PSV" is a basic consequence event, its properties can be seen on the interface of Figure 6.
After modelling the components and visualizing the adverse consequences with the fault trees, the last step is to do some calculations. Figure 7 shows the interface where different output results (or calculations) can be selected.

![Figure 7 Calculation window](image)

The selection tab of the output result window contains all the information for setting up a calculation. The top left indicates the type of calculation to be performed, with various options pertaining to the particular calculation in the top right. The bottom half of the window allows selection of the top event, the part of the tree and the station component for which the calculation will be performed.

Figure 8 shows a risk calculation, with its results superimposed over the station diagram.
CONCLUSION

The collaboration of Gaz de France, N.V. Nederlandse Gasunie, E.-ON Ruhrgas and SNAM Rete Gas S.p.A. has not only been a success as regards the sharing of knowledge and experience, but has also been very fruitful in terms of results. Indeed the WGCS has not only achieved its two main objectives, the development of a common methodology and its implementation in a prototype software, but has also generated new ideas. The group is planning to work on future enhancements of the software to allow an even more precise and accurate analysis of compressor stations.

Moreover the WGCS is also thinking of applying the software to different types of plants of gas transmission chain, such as gas reduction stations. One of the objectives of the group, therefore, is to increase the collaboration with other partners. An improved exchange of safety information will help to achieve the main goal of all gas transmission system operators: a safe, reliable and sustainable transport of gas.

ACKNOWLEDGEMENTS

The author and co-authors of this paper would like to express their gratitude to their colleagues of the research, safety and operational departments who have been involved in this project, not only for the work they have carried out but also for contributing to the successful collaboration between their four companies. Tessella Support Services plc. is acknowledged for the quality of the software it has developed.
REFERENCES

[3] DNV, 2000, Failure rate assessment of compressor fault tree’s basic events
[4] DNV, 2000, Compressor fault tree basic events data