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Model for quantitative risk assessment on naturally ventilated metering-regulation stations for natural gas

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ABSTRACT

The paper presents a model for quantitative risk assessment on metering stations and metering-regulation stations for natural gas with natural ventilation. The model enables the assessment of risk for people who live in the vicinity of these stations and complements the existing models for risk assessment on natural gas pipelines. It is based on risk assessment methods suggested in relevant guides, recommendations and standards. Explosion and jet fire are considered as major hazardous events and are modelled according to analytical models and empirical data. Local or other accessible databases are used for modelling of event frequencies and ignition probabilities. A case study on a sample station is carried out. For each hazardous event, fault tree and event tree analysis is performed. Results show influence of each hazardous event on the whole risk relative to the distance from the hazardous source. Ventilation is found to be a significant factor in determination of risk magnitude; its influence on individual risk is presented in a quantitative way. The model should be of use for pipeline operators as well as for environmental- and urban planners.

1. Introduction

A metering-regulation station (MRS) for natural gas is a facility for measurement and regulation of mass flow, pressure and temperature of natural gas that is transported through pipelines. MRS objects are thus technologically connected to the transmission pipeline for natural gas and are located at regular intervals along the transmission line. Apart from monitoring the gas flow in the transmission pipeline, MRS serves as a gas preparation facility for the distribution pipeline network. In the latter case the gas pressure is reduced and the gas is odourised in MRS before it reaches the end user. Stations where only measurement of gas parameters is carried out are referred to as metering stations (MS).

A pipeline operator manages MRS in accordance with relevant safety codes and standards.

The presence of natural gas as well as potential ignition sources in MS and MRS area represent risk for people and material property. A hazardous event (i.e. gas leakage and its ignition) on buried pipeline usually results in jet fire; the latter is a form of fire that evolves from combustion of gas emerging from an orifice with a significant momentum (CPR 18E). Other effects such as fireball or flash fire are also possible, but are rare due to the buoyant nature of natural gas and are usually included in the calculation of heat radiation from a sustained jet fire, which has a predominant reach (Jo and Ahn, 2005). The same event inside MS or MRS building can provoke explosion of gas–air mixture due to the confinement of the flammable cloud. It is the explosion inside the confined MS or MRS object that poses the main risk to the (potentially inhabited or populated) surroundings of that object.

Risk is generally defined as a measure of severity and likelihood of damage due to unwanted hazardous events. It is usually expressed in the form of the following equation (CSChE, 2004):

$$\text{Hazardous event risk} = \text{Hazardous event frequency} \times \text{Hazardous event consequence} \quad (1)$$

The hazardous event frequency denotes the annual probability of the event occurrence, while the hazardous event consequences denote the magnitude of damage to the receptors should that event occur.

Hazardous event risk is usually expressed in terms of individual risk. The latter is defined as the probability that in 1 year a person will become a victim of an accident (hazardous event) if the person remains permanently and unprotected in a certain location (CPR 18E, 1999). Assessment of individual risk requires the application of quantitative risk assessment (QRA) methods. This is especially important for determination of proximity distances between MS/MRS objects and residential buildings in order to ensure allowable risk level for people living in these buildings. Allowable limit risk level is generally determined by relevant legislation; in Europe,

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the generally acceptable value for allowable individual risk level is equal to 1.0×10^{-6}/year, which usually applies also for hazards other than events on natural gas pipelines (Duijm, 2009; Jonkman et al., 2010). Pipeline operators should therefore assess and manage individual risk when planning and operating the pipeline and its facilities in order to comply with the legislation. On the other hand, the acceptable level of societal risk, i.e. the frequency per year that a group of at least a certain size will at one time become victims of an accident (CPR 18E, 1999), is not always prescribed by legislation. However, the same methods can be applied to evaluate both types of risk if required.

Despite of the low frequency of hazardous events (i.e. the uncontrolled leak of gas and its subsequent ignition), the pipeline operator should focus on continuous improvement of safety conditions in MS and MRS. The operator is also obliged to carry into effect the operational procedures that enhance the protection of people (employees and third persons) and environment. For this purpose, it is important for the operator to be capable of assessing the level of risk in order to deal with it appropriately.

Several codes and standards emphasise the need for risk assessment on transmission pipelines with natural gas as well as on pipeline facilities, such as MS and MSR (ASME, 2004; CSChE, 2004; EN 1594, 2000). However, they do not provide sufficient information or guidelines to calculate or assess the actual risk level, which is particularly true in the case of QRA. Pipeline operator should therefore make use of commercial risk models (if available) or develop their own according to relevant recommendations and guidelines for QRA (i.e. CPR 18E, 1999). While basic principles to develop a QRA model for natural gas pipelines are frequently dealt with in relevant literature (Mather et al., 2001; Jo and Ahn, 2005; Jo and Crowl, 2008; Han and Weng, 2011), it is not so with the models for MS or MRS objects, even though the individual risk in their vicinity can be considerably higher than those from the buried pipeline. The operator is left with some guidelines that usually result in qualitative risk assessment only. Ones of the most notable and widely used guidelines of this kind are the IGEM recommendations (IGEM, 2010). They enable the classification of the confined space of MS or MRS object into one of several explosion zones; the latter are characterised by the probability of occurrence of explosive atmosphere inside the confined MS or MRS object. The IGEM guidelines are therefore useful for qualitative risk assessment for people within the explosive atmosphere (i.e. employees and workers who are present in MS and MRS objects only at inspection intervals for a few hours), but they cannot be sufficient to predict the distribution of risk levels outside the MR or MRS building for residents in the vicinity of such a facility. While IGEM recommendations could still be applicable for the determination of the hazardous event frequency (Eq. (1)), other parameters, needed for QRA procedure (i.e. event consequences, ignition probabilities etc.), must be modelled or derived from other sources or processes.

The paper focuses on a simple QRA model for MS and MRS that enables the basic assessment and monitoring of risk levels imposed by hazardous events in MS and MRS objects to the residents outside the MS/MRS site.

2. QRA model concept for MS and MRS

An MS or MRS object is usually a closed (confined) building, which comprises the required installations for gas measurements and regulation. Typical elements that are potential sources of gas leakage in the inner space of a MS/MRS object and should be taken into consideration in the QRA model are:

- ball valves;
- manometric valves;
- pressure regulators (in MRS);
- safety block valves;
- safety release valves;
- check valves;
- flanges;
- screwed joints.

Apart from gas leakages inside the MRS object, a considerable amount of gas can be released through safety release valves to the outer atmosphere outside the MRS building. Such releases can occur during normal operation in case of inlet gas pressure fluctuations or in case of the pressure regulator malfunction or failure. Containers of the gas odouriser that are usually stationed outside of the plant building can represent another source of leakage. Tetrahydrothiophene (THT) is mainly used in Europe as a gas odorant (de Wild et al., 2006). THT is flammable, but due to relative low amounts and the fact that the odouriser is often not present in the plant (particularly in MS), its influence on overall risk is excluded from this study.

Fig. 1 shows the schematic algorithm of the proposed individual risk model for MS and MRS objects with regard to populated buildings in the vicinity of MS and MRS.

While the major cause for incidents on natural gas pipelines are third-party interferences (EGIG, 2011), these are virtually negligible in MS/MRS buildings; therefore, vandalism, terrorist actions, and errors of occasional workers are excluded at this stage. The main reason is that as opposed to buried pipelines the MS/MRS objects are visible to all and their sites are protected by fence and visual warnings. Inside the MS/MRS buildings the installations are above ground as well and are regularly inspected by authorised workers. However, due to large amount of joints and mechanically operating elements, gas leakages are likely to occur. The main hazardous event that can be provoked by gas leakage and its subsequent ignition in the inner confined space of the MRS object is explosion (CPR 14E, 2005). Due to confinement inside the building, flash fire could occur only in very early stages of gas release, if ignited soon enough, when the confined space is not yet filled with flammable mixture (CPR 18E, 1999); this can be harmful to workers inside the building (if present), but would have no effect on people outside the MS/MRS building due to small amount of released gas prior to ignition and a short duration of the event. The instantaneous ignition of gas (i.e. at the beginning of leakage, when the inner space is not yet filled with leaking gas) that could provoke a jet fire inside the MRS building is neglected here, for the IGEM guidelines (IGEM, 2010) specify/recommend a hole size for gas leakage calculations not greater than 0.25 mm^2; heat radiation of a jet fire from such a small hole would be negligible even at gas pressures above 100 bar.

The exhaust pipes for the released gas from safety release valves are normally mounted on the outside wall surface of the MRS object. The gas pressure fluctuations during normal operation cause only small amounts of released gas for very short periods (usually not longer than a few seconds) and are therefore excluded from this study. On the other hand, the failure of a pressure regulator can force large amounts of gas to be released continuously for longer time period through the safety release valve to the outer atmosphere (comparable to a gas jet from a hole in a gas pipeline). Since the release orifice of a safety release valve has a diameter of several tens of millimetres, a jet fire can occur from the exhaust pipes with a heat radiation that cannot be neglected. Risk assessment regarding MRS buildings is therefore required for both, inner- and outer space. An MS object does not have any regulators, so the occurrence of a jet fire on the outer wall of the MS building is excluded from the study.

Analyses of consequences and frequencies of hazardous events for QRA require the application of relevant relations, equations or