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Quantitative risk assessment of the Italian gas distribution network

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ABSTRACT

European Critical Infrastructures include physical resources, services, information technology facilities, networks and infrastructure assets, which, if disrupted or destroyed would have a serious impact on the health, safety, security, economic or social well-being of the Member States.

The gas distribution network is a critical infrastructure and its failure can cause damage to structures and injury to people.

The aim of this paper is to analyze and then assess the risk of the Italian high pressure natural gas distribution network.

The paper describes an application of a methodology for quantitative risk assessment.

Failure frequencies considered in risk calculation were found in the European Gas pipeline Incident data Group (EGIG) database, whereas consequences were computed as a function of pipe diameter and operating pressure for each section of the network. The results of this quantitative risk assessment is the determination of local and social risks for the Italian North East Area.

1. Introduction

European Critical Infrastructures include those physical resources, services, information technology facilities, networks and infrastructure assets, which, if disrupted or destroyed would have a serious impact on the health, safety, security, economic or social well-being of the Member States.

The gas distribution network is a critical infrastructure and its failure can cause damage to structures and injury to people.

The quantity of natural gas transported in the European Union and in the industrialized Countries is progressively increasing. As the volumes of gas transported from one site to another is increasing, also the awareness of the risk posed by these activities has grown within the operators and the population potentially exposed (Erkut & Alp 2007; HSE 1991, p. 68; Kara & Verter, 2004).

Therefore, the problem of the safety and security of the natural gas distribution infrastructure must be adequately investigated.

Despite the low number of accidents that occurred in the transportation of natural gas (CCPS 1995, p. 382; TNO, 1999), some serious incidents have confirmed that the transportation of hazardous materials has the potential to pose a high risk to the population.

Two particularly relevant pipeline incidents occurred in 2004: the explosion of a major underground high pressure natural gas pipeline in Ghislenghien industrial park, near Ath, about 50 km (30 miles) south-west of Brussels, Belgium (HInt Dossier, 2005) and a pipeline rupture (ammonia) near Kingman, Kansas (http://www.ntsb.gov/investigations/fulltext/PAB0702.htm).

Other incidents involved road and rail transportation of fuels, such as in Viareggio (Italy) (Landucci et al., 2011) and Lac Mégantic (Canada, 2014).

The safety aspects of pipelines conveying dangerous substances are not covered in specific EU regulations. It must be highlighted that the Seveso III Directive (DIRECTIVE 2012/18/EU) aims to prevent major accidents at industrial facilities, whereas transport by pipeline is not included. Pipeline safety is else not included in other EU regulations such as the Pressure Equipment Directive (PED).

Already during the discussion on the Seveso II Directive, the European Parliament was keen to have pipelines included and the Commission was asked to look into the subject. At that time, the conclusion that emerged from the studies pointed out certain gaps in national legislation. These considerations, coupled with historical data, have led researchers of many countries to explore and evaluate transfers of hazardous materials by different transport modes (road, rail, waterway, pipeline, sea and air) with quantitative risk analysis (QRA) methodologies.

In fact, the same kind of accidental scenarios, in terms of frequency and severity, may occur both in fixed plants and in transportation systems. Additionally transport accidents may occur close to, and sometimes within, densely populated areas (Fabiano, Currò, Palazzi, & Pastorino, 2002).

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The development of tools both for the risk assessment and the performance evaluation of preventive and protective measures in the transportation of hazardous materials is thus an issue of primary concern. The results of several comprehensive quantitative risk assessments in areas where a high concentration of sites handling and storing hazardous substances is present, confirm the significant contribution of transportation hazards on the definition of the overall risk profile (Bubbico, Maschio, Mazzarotta, Milazzo, & Parisi, 2006; Egidi, Foraboschi, Spadoni, & Amendola, 1995; Milazzo, Lisi, Maschio, Antonioni, & Spadoni, 2010). In particular for the transport of substances via pipeline, these data are confirmed through accidental historical analysis (Brito & Dealmeida, 2009; CONCAWE, 2011; Dziubinski, Fratczak, & Markowski, 2006; EGIG, 2011; Montiel, Vílchez, Arnaldos, & Casal, 1996; OGP, 2010).

Risk-based optimization of the design of on-shore pipeline shutdown systems is described in Medina, Arnaldos, Casal, Bonvicini, & Cozzani (2012).

Several of such studies pointed out that the risk due to transportation activities is comparable or even more critical than the risk due to fixed installations. Several of such studies pointed out that the risk due to transportation activities is comparable or even more critical than the risk due to fixed installations. For this reason, some comprehensive methodological approaches for transportation risk analysis were proposed (Center for Chemical Process Safety, 1995, p. 382; Han & Weng, 2010; Health and Safety Executive, 1991, p. 68; TNO, 1999).

A natural gas pipeline is designed to allow gas transport from locations situated at large distances. The characteristic size of a gas transmission pipeline can range up to several hundred centimetres in diameter and several thousand kilometres in length. The pipeline may cross both rural and heavily population areas. Failure of the pipeline can lead to various outcomes, some of which can pose a significant threat to people and buildings in the immediate proximity of the failure location.

This paper presents the risk assessment of the Italian gas distribution network, specifically focuses on the methodologies and results of a quantitative risk analysis.

Section 2 describes the properties of natural gas and the characteristics of transportation by pipeline.

Section 3 describes the adopted risk analysis methodologies and they are been implementation to this case study.

In Section 4 a quantitative risk analysis (QRA) of the Italian NG distribution network is carried out.

In particular, the study aims to show the results of local risk and societal risk for the case study, and then the obtained results are compared with acceptability criteria.

2. Natural gas transport by pipeline

2.1. Natural gas

The natural gas distribution network is considered conventional in that its presence and use of this substance takes place from 19th century.

Currently natural gas is transported in gaseous phase by pipelines or in the liquid state by tankers (LNG).

Natural gas exists in nature under pressure in rock reservoirs in the Earth's crust, either dissolved in heavier hydrocarbons and water or by itself. Natural gas is colourless, odourless, tasteless, shapeless, and lighter than air.

The main component principal constituent of natural gas is methane, about 70–90%. Other components are light paraffinic hydrocarbons such as ethane, propane, and the butanes. Many natural gases contain nitrogen as well as carbon dioxide and hydrogen sulfide (Saeid Mokhatab, Poe, & James, 2006). Natural gas is treated to remove carbon dioxide, nitrogen and hydrogen sulphide, which is a toxic and corrosive gas.

During last decades, in the natural gas supply chain, the contribution of liquefied gas (LNG) has increased. To produce LNG, natural gas is piped from the wellhead to a liquefaction plant at a coastal location and then it is cooled at very low temperatures (approximately −160 °C).

The LNG is then loaded into specialized LNG tankers and shipped. Upon reaching its destination, the LNG is offloaded at a receiving terminal and re-gasified to be delivered into the local pipeline and storage network. Within this network, the transported gas becomes completely integrated with the locally produced or pipeline-imported natural gas supplies.

The properties of Natural Gas are shown in Table 1.

Since LNG and NG are the same substance, they have the same properties and the only difference is their relative density.

Mixed with air, methane is flammable in a concentration range from 5% to 15%. Below 5%, the amount of natural gas is not sufficient to support combustion, while above 15% there is not enough oxygen. At a temperature of 15 °C and atmospheric pressure, 1 cubic metre of methane generates over 33.5 MJ. Under these conditions, 1 cubic metre of natural gas has an energy content equal to 1.2 kg of coal and 0.83 kg of oil.

2.2. The Italian national gas pipeline network

The transport of natural gas in Italy is an integrated service which involves the transport of the gas delivered to Snam Rete Gas S.p.A. at the entry points of the National Network (connected with the Import lines from Russia, Northern Europe and North Africa, with the re-gasification plants and the production and storage centres located in Italy) up to the redelivery points of the Regional Network, (connected to local distribution utilities and large industrial and power plants) where the gas is redelivered to the users of the service.

The natural gas injected into the National Network originates from imports and, to a lesser extent, the national production. The import gas is injected into the National Network via eight entry points where the network joins up with the import pipelines (Tarvisio, Gorizia, Passo Gries, Mazara del Vallo, Gela) and the two LNG regasification terminals (Panigaglia, Cavarzere). Domestically produced gas is introduced into the Network through 51 entry points from the production fields or their collection/treatment plants; natural gas storage fields are also connected to the transmission network.

Legislative Decree no. 164 of 23 May 2000 (the so-called Letta Decree) divided the Italian pipelines network into a National Gas Pipeline Network (of approximately 8800 km) and a Regional Transmission Network (of more than 22,600 km). The National Gas

Table 1
Properties of natural gas.

Properties	Value for NG
Relative molar mass	17–20
Relative density NG, 15 °C	0.72–0.81
Relative density LNG, 15 °C	424.2
Boiling point, °C	−162
Vapour flammability limits, volume %	5–15
Flammability limits	0.7–2.1
Lower heating/calorific value, MJ/kg	38–50
Autoignition temperature, °C	540–560
Octane number	120–130
Methane number	69–99
Stoichiometric lower heating value, MJ/kg	2.75