ITALIAN UNDERGROUND GAS STORAGE ACTIVITIES: RISK MANAGEMENT AND SAFETY ASPECTS

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Abstract. *The underground storage of natural gas is an industrial process that consists of injecting gas into a depleted underground rock system to ensure its accumulation and subsequently deliver it in a second phase. The scope of the paper is to provide technical support in the safety analysis evaluation of underground natural gas storage establishments, aiming to achieve uniformity of evaluation throughout the national territory, under the Seveso III directive. The main issues concern: Italian law and legal requirements; information about the establishment and the company organizational structure; information on classification of substance under the Seveso directive; industrial safety of the plants, with the relative identification of the critical technical systems; methodological approach for assessing the risk analysis of plants, including the NaTech risk. Some references are finally given to identify the most "critical" parameters of the different techniques for risk analysis, which, if not adequately evaluated, can lead to an incorrect result of the analysis itself, also considering the correct safety measures to prevent or limit the consequences of an accident scenario, and about the proper implementation of the Safety Management System.*

Key words*: Seveso, Underground, Safety, Risk.*

1. Introduction

In the context of technologies aimed at supporting the national energy transition, underground natural gas storage facilities play a crucial role in addressing variable market demands or situations of energy supply shortages. The paper explains the results of technical assessments carried out by the national competent authorities working group, under the D.Lgs. 105/2015, the Italian implementation of the 2012/18/UE directive ("Seveso III"), regarding risk management and safety aspects in underground natural gas storage activities. The scope is to provide technical support in evaluating safety reports for these facilities, aiming to achieve uniformity in assessments throughout the national territory, taking into account plant and site-specific territorial aspects. The paper explains the main contents of the "Guidelines for the safety report evaluation of underground natural gas storage" [1], whose purpose was to have uniform evaluation throughout the national territory of the risk analyses produced.

Depending on the amount of dangerous substances present, establishments under the D.Lgs. 105/2015 are categorised in lower and upper tiers, with different obligations to prevent major accidents and to limit their consequences for human health and the environment. The requirements include, among others: notification of all concerned establishments; deploying a Major Accident Prevention Policy (MAPP) and a Safety Management System (SMS); producing a Safety Report (SR) for upper-tier establishments; producing an Internal Emergency Plan (IEP) for upper-tier establishments; and providing information in case of accidents. In Italy, based on the information in the inventory of establishment notifications, there are about 1.000 Seveso sites. Among these, twelve underground natural gas storage sites operate in four different regions in the central north of the country.

The operating storage sites are depleted gas production sites: natural structures in which gas was trapped and which, once the primary exploitation phase was completed, were converted into storage. These establishments are: surface plants (compressor and treatment units); reservoirs (deposits – natural storage systems); wells (connecting the reservoir with surface plants); interconnecting flow-lines. The activity consists of the storage of natural gas in underground geological structures (injection) and subsequent distribution, according to market demand and to guarantee the "strategic" energy supply in the country. The substances classified as dangerous under D.Lgs. 105/2015 present in these establishments are natural gas, diesel oil, and methanol. The Italian establishments are upper-tier establishments for the quantities of natural gas held, considering the holdup of the reservoir and the holdup of the surface plants. For underground storage of natural gas, the following additional legal references may apply: the D.Lgs. 624/1996, concerning the safety and health of workers in extractive industries; the DM 17 April 2008, which applies to gas transport pipelines; the DM 17 January 2018, which provide the Italian regulatory indications for constructions, seismic verification and other structural checks (i.e. strong wind and flooding).

In the safety report, the site operator produces a risk assessment with the description of a risk analysis and measures for the prevention of major accident hazards. The Italian competent authority for the evaluation of the safety report carries out the technical evaluation for the safety report with a multidisciplinary approach. The technical evaluation identifies accident scenarios, damage distances and frequencies of occurrence, as well as the safety measures adopted, for External Emergency Planning (EEP) and Land Use Planning (LUP).

2. Guidelines for the safety report evaluation of underground natural gas storage

The guidelines do not introduce new developments, but it is the result of the experience gained over the years at a national level in the evaluation of the Safety Reports of this type of establishment. The specificity of these plants is that the safety of the underground storage is ensured by the production history of the field itself, as the geological covering structures have guaranteed the permanence on site of the gas for millions of years, and it is also managed by creating specific site geo-mechanical models and adopting monitoring techniques.

The main contents of the guidelines are: Information relating to establishment; Establishment classification and verification subject to Seveso directive; Safety of establishment; NaTech risk assessment; Identification of events and accident scenarios; Evaluation of events and scenarios frequency; Calculation of consequences; Safety systems.

3. Safety of Natural Gas Storage Establishments

There are two parameters for the safety assessment of gas reservoirs, considering a depth of 1000-2000 m: the geo-mechanical model for the gas reservoir provides quantitative assessments of the limit pressure with which safe storage can be performed; monitoring of pressure, micro-seismicity and deformation of the soil indicate the maintenance of the state of the gas reservoir in conditions of safety during injection and distribution activity. The well consists of “casing”, steel pipes, and a cement filling. Anomalies with gas leakage that can cause risks are: ineffective seal from the casing cementation of the well; risk of eruption (blowout) of the well, even during maintenance operations.

Flow-lines are connection pipelines, outside the fences of the plants, between the well/cluster areas and the surface plants (compressor units). In Italy, the “methane pipeline” standard establishes the minimum safety distances from residential areas: 100 m for pipelines with maximum operating pressures exceeding 24 bar. Concerning flow-lines, in the safety report, it is therefore important to describe: routes and construction features; interception – blocking – safety systems. Another aspect to be taken into consideration, to correctly evaluate the safety of flow-lines, is the formation of hydrates that could obstruct the pipeline. Hydrates are compounds of molecules of free water and/or condensation in the pipeline and natural gases that crystallize under specific conditions of pressure and temperature. To contrast the formation of hydrates, inhibitors such as methanol or glycol are used to move the stability curve. The evaluation of hydrate formation that can lead to variations in pressure or temperature must be done in all plant conditions (normal operation, shutdown, maintenance activities). It is then necessary to implement a procedure for the formation of hydrates and emergency instructions if the phenomenon occurs.

4. Risk analysis for surface plants and Safety Report evaluation

For the identification of events and consequent accident scenarios, it is possible to refer to the typical techniques as historical experience, what-if analysis, FMEA-FMECA, and HazOp. The analysis develops as: internal historical analysis, identifying causes of accidents, near-misses, anomalies that have occurred inside the plant; external historical analysis of events, which have occurred in similar establishments, through consultation of updated databases (MHIDAS, FACTS, eMARS, etc.); analysis of the historical experience of "delivery points" or "nodes" of the national natural gas distribution network. Care must be taken on reference databases and plant and/or management measures to prevent events or limit their probability and consequences.

The identification of failure rates differs according to complex systems (Fault tree analysis) or “Random” failure of a single component (equipment, systems, pipes). Failure rates are taken from reliability databases (Oreda, EIGIG, HSE, TNO Purple Book, EIGH, etc.): it is important to show that the data are representative of the specific plant and that the chosen failure rates can be considered conservative. In underground gas storage plants, the random failure of the pipes is the basis (Top-Event) of the most significant events (more extensive damage areas). In the case of above-ground pipes [2], the guidelines make a comparison between databases (HSE Failure Rate/TNO Purple Book 2005), giving general frequency values for pipe failure in a range of 10-5 – 10-7 occ/y*m [3]. For buried pipes, an important reference is the European Gas Pipeline Incident Data Group (EGIG) Report [4]. The guidelines suggest, however, that failure frequencies indicated in the EGIG Report can be taken as a reference for natural gas pipes (buried or not buried, even within establishments) [5]. Final consideration must be made on the incidence of the different failure causes in frequency. For example, the CONCAWE Report identifies the percentage of failure causes for buried pipes carrying hot or cold petroleum products (2011-2016 period) as below: corrosion (90% – hot products; 20% cold products), operational errors (10% – cold), and mechanical causes (20% – cold) [6].

The reduction of occurrence frequencies through an integrated analysis that combines risk analysis with the Safety Management System (SMS) allows the quantification of the positive effects of the system in order to prevent major accidents. If an inspection plan of equipment and pipes based on risk analysis has been prepared, its effectiveness in preparing an integrated analysis can be considered in order to reduce the frequency of accidents. The use of methodologies for the drafting of a risk-based inspection plan, such as the API 581: 2016 standard, is suggested. If this standard is used improperly and partially (e.g., considering in a generic way only SMS procedures), the results that are obtained will be wrong, because there will be a reduction by at least one order of magnitude of the general frequencies of equipment and pipe failure. These methodologies allow the reduction of the top frequencies for complex systems – Fault Tree Analysis [7], and specifically for random pipe failures [8]. Taking for example, the parameter "external corrosion", the quantification of this reduction is obtained by applying the methods indicated [9]. For the calculation of scenario frequency using the event tree [2], it is finally important to remember that the trigger probability values (immediate or delayed triggering) must be pertinent to the plant reality or cautiously estimated in favor of safety [10].

It is necessary to model the physical phenomena of methane release in high-pressure conditions. These are the release phases: Phase 1: expansion from the initial pressure to the hole pressure; Phase 2: expansion up to atmospheric pressure; Phase 3: initial dilution. The methane released is in supercritical conditions, that is, a fluid is at a temperature and pressure higher than the critical ones (no distinction between gaseous and liquid phase). The properties are intermediate between those of a gas and a liquid, and its density can be greater than that of gases under ordinary conditions. The density of methane proportionally affects the release rate, and therefore, the gas release rate must be calculated considering the gas density in supercritical conditions. The possible accident scenarios in case of methane release in the conditions stated above are: Flash Fire. Fire of a flammable gas cloud that disperses into the atmosphere as a light neutral gas; the factors that affect modelling are density, weather conditions, release duration, cloud dilution, and roughness. In case of interception systems, the duration of the release and the quantity released will be less: the frequency of the flash fire scenario could be reduced, as the smaller cloud is less likely to run to a trigger source. Therefore, the intervention times assumed must be consistent with the emergency procedures and be verified through field inspections; Jet Fire. The release of a pressurized gas with immediate ignition and fire of a cloud; the factors that affect modelling are gas density, jet direction, and release flow rate. Jet fire damage areas are normally included within the damaged areas for the corresponding flash fire scenarios: they must be considered especially for the purposes of evaluating a possible domino effect, Vapour Cloud Explosion (VCE). It occurs when a confinement of the mass of flammable vapors is mixed with air at the moment of ignition. It is necessary to assess whether the air/natural gas mixture can fall within the flammability range, calculating the amount of flammable mixture between LFL (Lower Flammability Limit) and UFL (Upper Flammability Limit). Conditions that facilitate the occurrence of a VCE are releases in areas with a high degree of confinement or in closed environments. The verification of the computational models chosen for the estimation of the consequences must be adequate to the physical phenomenon reality: some models do not consider the “supercritical conditions” of methane. Some software does not automatically consider the initial expansion and dilution of the methane jet. It is therefore necessary to apply a dilution factor to the release range (approximately 1/10): the value of the recalculated flow must be used as input data to any Gaussian dispersion model, since for this model the gas concentration is directly proportional to the release flow.

The main prevention and protection measures aimed at reducing the frequency and/or extent of the consequences of accident events are: Locking systems to make plants safe (ESD – Emergency Shut Down: closing of all the plant sectioning valves and opening of the blow down valves with the consequent depressurization of the system; PSD – Process Shut Down: production shutdown by closing the sectioning valves (SDV) and securing the unit; LSD – Local Shut Down: blocking and securing of the unit, or interception and stopping of the single equipment); Fire prevention measures and systems.

Finally, a numerical example can be useful to understand the conditions of use of commercial computational models for the study of the consequences in case of supercritical conditions of methane releases. A flash fire, caused by failure of a natural gas pipe (152 mm hole) at an operating pressure of 140 bar (top-event), was developed through geo-referencing of the consequence evaluation. The calculation was carried out under the following weather conditions in the area: atmospheric stability class of Pasquill D5 (neutral) with a wind speed of 5 m/s. The damage distances resulting are 284.91 m (corresponding to "LFL" threshold) and 435.88 m (corresponding to "1/2 LFL" threshold).

5. Conclusions

Underground natural gas storage establishments use depleted fields as a natural reservoir to store gas and therefore constitute strategic energy reserves. The purpose of the document is to provide technical support with reference to the evaluation of the Safety Reports of the underground natural gas storage establishments, to pursue greater uniformity of assessment throughout the national territory. Although each installation may present strictly site-specific plant and territorial aspects, there are nonetheless elements that unite all installations. The "Guidelines for the safety report evaluation of underground natural gas storage" provide specific indications and insights to support and direct the activities related to the assessment of the risks of a major accident. Legislative Decree 105/15 defines criteria, data, references, information for the preparation of the Safety Report and assigns the manager the task of identifying the dangers of major accidents and measures; consequently, it is up to the manager to choose the methodology to be used for the systematic identification of accidents, the evaluation of probability/frequencies and the calculation of the consequences, since this methodology must be justified and technically justified in the Safety Report. Instead, the competent Authority is responsible for "ensuring that the description of each scenario, complete with supporting evidence, is formulated in such a way as to highlight the consistency between the identified scenario and the measures taken". The approach used for drafting the guidelines initially envisaged the search for the references of technical regulations applicable to underground gas storage, including an overview of the approaches adopted in some European countries for the assessment of the risk of a major accident; subsequently, the problems relating to the reservoir and wells were examined, to finish with an in-depth study of the peculiar characteristics of the surface plants, considering the related safety aspects concerning major accidents, including the NaTech because of the extension of these establishments over large areas subject to extreme weather events.

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