“Seminar on Seveso Implementation Challenges”
Sibiu (Romania), 15-16/05/2019

“Underground natural gas storage - Guidelines for the evaluation of Safety Reports”

Challenges in risk assessment and the development of risk assessment guidelines for competent authorities for underground gas storage activities in Italy

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ARPAE and ISPRA for industrial control

- ARPAE is the technical body supporting the Italian Regional authority of Emilia Romagna in Seveso issues:
  - Regional Laws
  - Cooperation in National Laws
  - Regional Inventory of establishments
  - Technical evaluation of safety reports
  - Safety Management System (SMS) inspections
  - External Emergency Planning (EEP)
  - Land Use Planning (LUP)
  - Collaboration with other Authorities competent for industrial risk

arpae
agenzia prevenzione ambiente energia emilia-romagna

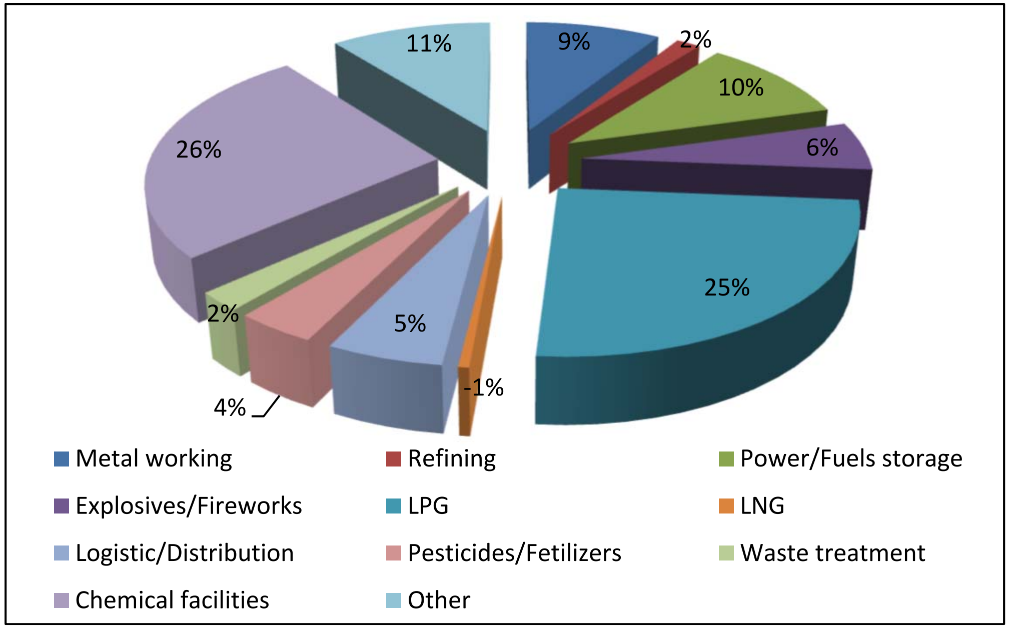
- ISPRA has a national role as a technical body supporting Italy's Ministry of Environment in the national implementation of the Seveso Directives (last: D. Lgs. 105/2015)
  - Laws and decrees
  - National Inventory of establishments
  - Safety Management System (SMS) Inspections
  - Support for international activities
  - Technical coordination of ARPA
  - Collaboration with other Authorities competent for industrial risk

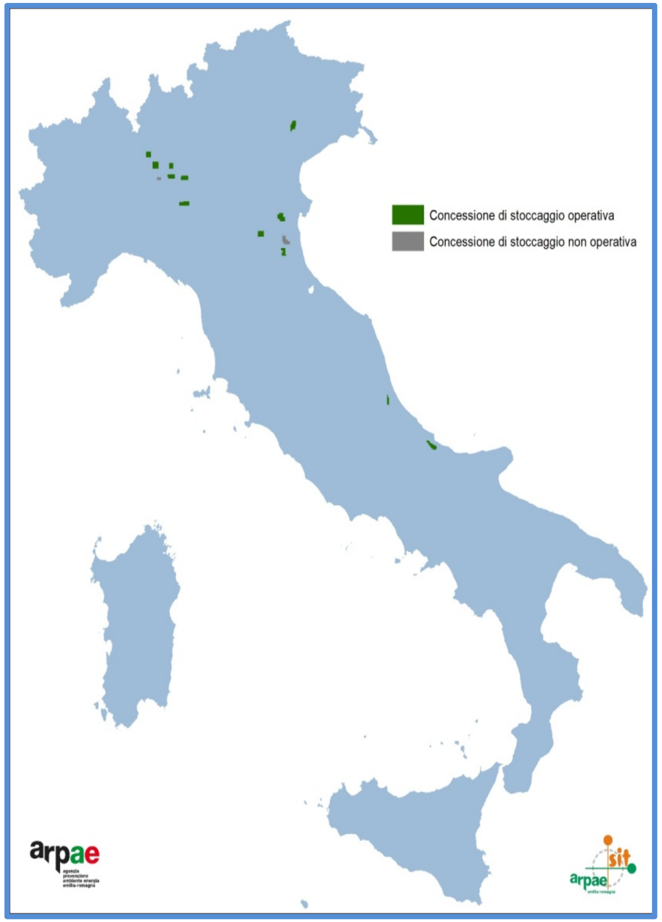
ISPRA
Istituto Superiore per la Protezione e la Ricerca Ambientale

Sistema Nazionale per la Protezione dell'Ambiente

Introduction and background

The Italian situation: 994 Seveso sites



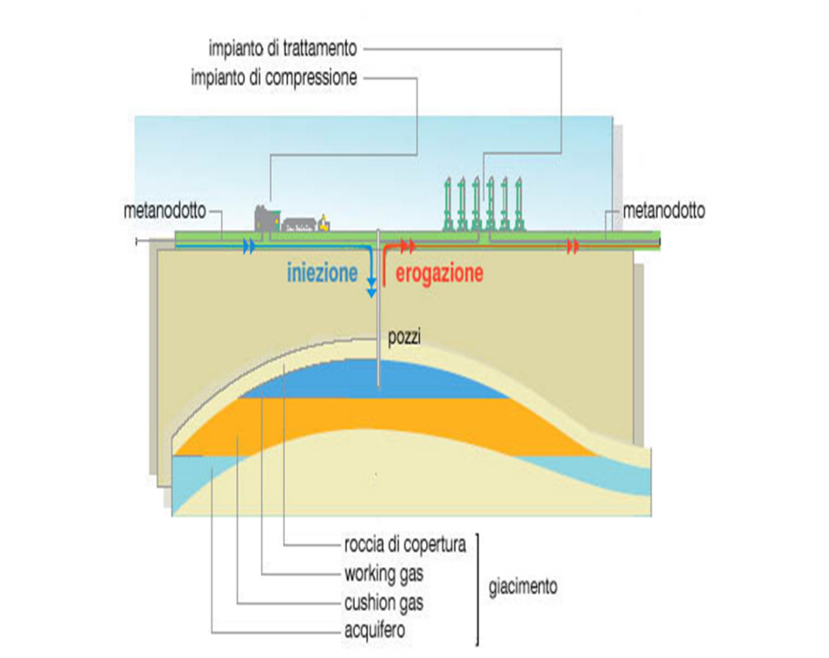


- *515 upper tier and 479 lower tier (31/12/2018)*

✓ **12 underground natural gas storage sites** operating in 4 different regions: Lombardia, Veneto, Emilia Romagna, Abruzzo

Underground storage in Italy

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” supply in the country

Risk assessment and safety reports

- ***Risk assessment***

  The site operator produces a safety report with a description of a risk analysis and measures for the prevention of accident major hazards

- ***The competent authority is: the Regional Technical Committee***

  The Regional Technical Committee (CTR) consists of the National Fire Brigade (VVF), the Regional Environmental Agency (ARPA), the Safety at Work Institute (INAIL), Regional and Municipal Authorities, the Local Health Authority (ASL) and the National Mining Office (UNMIG)

  – The committee nominates a working group of representatives from VVF ARPA and UNMIG 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 the purposes of External Emergency Planning (EEP) and Land Use Planning (LUP)

Guidelines for the safety report evaluation of underground natural gas storage: challenges, development and results

https://www.minambiente.it/sites/default/files/archivio/allegati/rischio_industriale/Linea_Guida_Stoccaggi_Gas_ottobre2018.pdf

Why the guidelines?

There are three main reasons why we wrote these guidelines

- *Establishments located in 4 different regions*
- *Discrepancies in the criteria to identify accident scenarios*
- *Discrepancies in consequence assessments (damage areas)*

Purpose ⟹

✓ To create shared guidelines in order to have uniform evaluation throughout the national territory of the risk analyses produced

Challenges ⟹

✓ To systematize the risk analysis experience gained over the years in the different regions

✓ To investigate rules and methodologies applicable to underground gas storage facilities

Who has drawn up the guidelines?

- In Italy there is a Coordination Table of Seveso Competent Authorities under the Ministry of the Environment (art. 11 L.D. 105/2015).
- The guidelines have been drafted by a specific working group which was nominated by the Coordination Table. This working group consisted of representatives from:
  - The Regional Environmental Agency (ARPA), The National Fire Brigade (VVF), the National Institute for Environmental Protection and Research (ISPRA), the Safety at Work Institute (INAIL), Region, the National Mining Office (UNMIG) and University
- The Guidelines provide technical indications for the evaluation of safety reports presented by the operators of underground natural gas storage sites

MULTIDISCIPLINARY APPROACH

Main contents of the guidelines

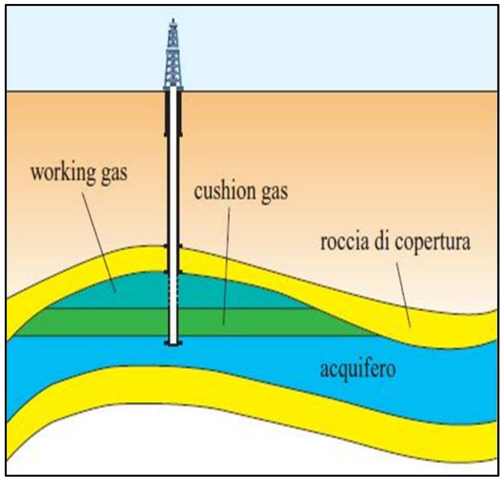
- **INFORMATION RELATING TO ESTABLISHMENT**
  - ✓ Activities: reservoirs; treatment units; clusters; isolated wells. Organizational structure.
- **ESTABLISHMENT CLASSIFICATION AND VERIFICATION SUBJECT TO SEVESO**
  - ✓ Quantities present: storage and hold up in reservoirs; surface plants; individual plants; other substances
- **SAFETY OF ESTABLISHMENT**
  - ✓ Risk: loss of integrity of reservoirs; wells Loss Of Containment (LOC); connecting flow-lines; formation of hydrates; Na-tech
- **IDENTIFICATION OF EVENTS AND ACCIDENT SCENARIOS**
  - ✓ Analysis of accident experience, preliminary analysis of critical surface plants
- **EVALUATION OF EVENTS AND SCENARIOS FREQUENCY**
  - ✓ Evaluation of frequency: events (fault tree and/or databases); scenarios (event tree)
- **CALCULATION OF CONSEQUENCES**
  - ✓ Identification of the source terms of the event; assessment of the release dynamics and calculation of the flow rate. calculation of consequences; evaluation of damage distances through mathematical models
- **SAFETY SYSTEMS**
  - ✓ Lightning protection measures; locking systems. fire prevention measures

Safety of Natural Gas storage establishments

Risk of loss of integrity of the reservoir
Geo-Mechanical Model

- ✓ There are two parameters for the safety assessment of the gas reservoir

Depth 1000-2000 m



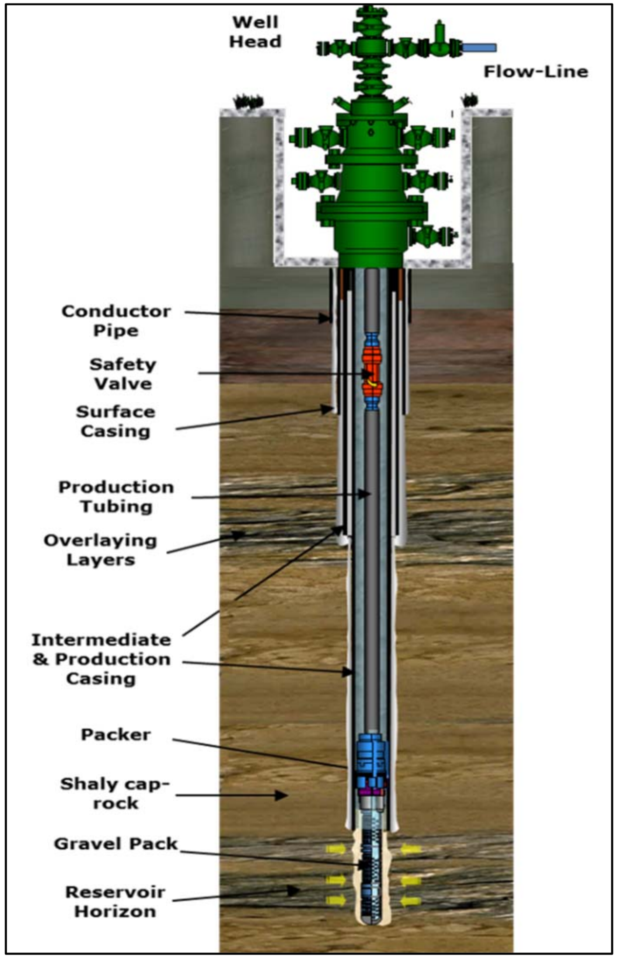
- ➢ The geo-mechanical model for the gas reservoir provides quantitative assessments of the limit pressure with which safe storage can be performed

- ➢ 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 the injection and distribution activity

Safety of natural gas storage establishments

Risk of loss of integrity of the reservoir and the wells

Well safety

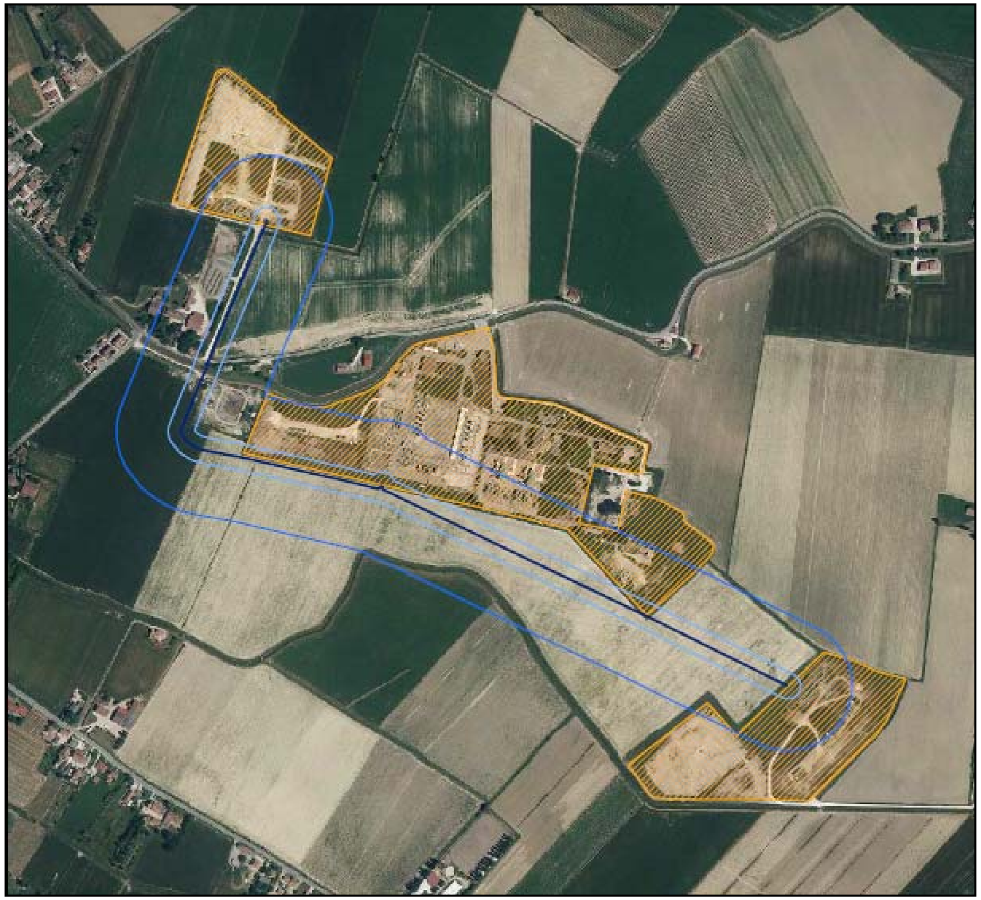


- ✓ The well consists of "casing", steel pipes and a cement filling
- ✓ Anomalies with gas leakage that can cause risks
  - ➢ Ineffective seal from the casing cementation of the well
  - ➢ Risk of eruption (blow out) of the well even during maintenance operations

Safety of natural gas storage establishments

Safety of connecting flow-lines

✓ *Connection pipelines, outside the fences of the plants, between the well/cluster areas and the surface plants (compressor units)*

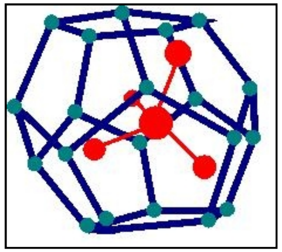


- In Italy the "methane pipeline" standard establishes the minimum safety distances from residential areas:
  - *100 m for pipelines with maximum operating pressures exceeding 24 bar*

- **(Guidelines) It is important to describe:**
  - ***routes and construction features; interception - blocking – safety systems***

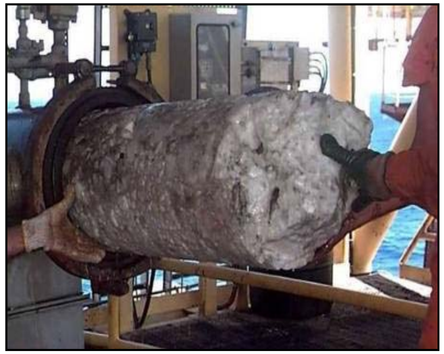
Safety of natural gas storage establishments

Safety of connecting flow-lines

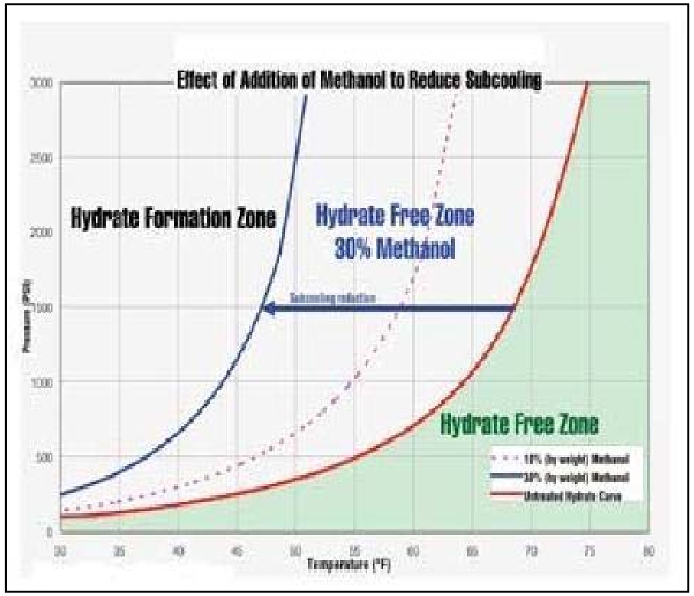


Methane hydrate
(methane molecule is red)

- ✓ Hydrates are compounds of molecules of free water and/or condensation in the pipeline and natural gasses that crystallize in particular conditions of pressure and temperature



Block of methane hydrate obstructing pipeline



- ✓ To contrast the formation of hydrates, inhibitors such as methanol or glycol are used to move the stability curve

- ❑ **The guidelines give indications for the evaluation of hydrate formation in all plant conditions, that can lead to variations in pressure or temperature**
  - **normal operation, shutdown, maintenance activities**

Procedure for the formation of hydrates and emergency instructions to be implemented if the phenomenon occurs

Safety of natural gas storage establishments

Na-Tech safety

Geophysical and lightning events, hydro-geological instability

✓ A Na-Tech risk analysis shows, for example, if parts of the plant are not sufficiently safe

❑ **The Guidelines identify:**

- **the actions to be implemented through an adjustment plan to make the establishment safe**
- **to proceed with the risk assessment through the identification of possible accident scenarios and the related damage areas**
- **prevention/protection measures that ensure the safety of the installation**

Risk analysis for surface plants

Identification of event and accident scenarios

Historical experience, what-if analysis, FMEA-FMECA, HazOp

- ✓ Internal historical analysis
  - ➢ Causes of accidents, near-misses and anomalies that have occurred inside the plant
  - ➢ Fires, explosions, emissions of dangerous substances that have occurred, formation of hydrates
- ✓ External historical analysis of events which haveoccurred in similar establishments
  - ➢ Updated Databases (MHIDAS, FACTS, eMARS, etc.)
- ✓ Analysis of the historical experience of "delivery points" or "nodes" of the national natural gas distribution network
  - ➢ Located in areas adjacent to the establishment and with which they are closely interconnected

- ❑ **The guidelines give indications on all reference databases and plant and/or management measures to prevent events or limit their probability and consequences**

Risk analysis for surface plants

Evaluation of the frequency of events and scenarios

Rate of failure identification → Complex systems → Fault tree analysis

Rate of failure identification → "Random" failure of a single component (equipment, systems, pipes)

Failure rates are taken from reliability databases
(Oreda, EIGIG, HSE, TNO Purple Book, EIGH, etc.)

- ✓ Limitation of the Database: attributing to a well-identified component the results found on other identical components, but whose use characteristics and operating environment conditions may be substantially different

- ❑ **The guidelines describe the reliability databases and suggests that it is important to show that 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)

Risk analysis for surface plants

General frequency values for pipe failure – examples

➢ Above-ground pipes

Diametri tubazioni Diametri Rottura	0"-2"		2"-6"		6"-11"		11"-19"		19"-39"	
	HSE	TNO	HSE	TNO	HSE	TNO	HSE	TNO	HSE	TNO
Circa 1/9"	$1*10^{-5}$		$2*10^{-6}$							
1/6"					$1*10^{-6}$		$8*10^{-7}$		$7*10^{-7}$	
1"	$5*10^{-6}$		$1*10^{-6}$		$7*10^{-7}$		$5*10^{-7}$		$4*10^{-7}$	
10% DN		$5*10^{-6}$		da $2*10^{-6}$ a $5*10^{-6}$		$5*10^{-7}$		$5*10^{-7}$		$5*10^{-7}$
Rottura totale	$1*10^{-6}$	$1*10^{-6}$	$5*10^{-7}$	da $3*10^{-7}$ a $1*10^{-7}$	$2*10^{-7}$	$1*10^{-7}$	$7*10^{-8}$	$1*10^{-7}$	$4*10^{-8}$	$1*10^{-7}$

*HSE Failure Rate/TNO Purple Book 2005: General frequency values for pipe failure [occ/(y*m)]*

❑ **The guidelines make a comparison between databases (HSE Failure Rate/TNO Purple Book 2005)**

✓ ***General frequency values for pipe failure***

✓ ***Order in a range of 10^{-5} – 10^{-7}***

➢ Buried pipes

10° EGIG Report (2018): Frequency values for gas pipe failure

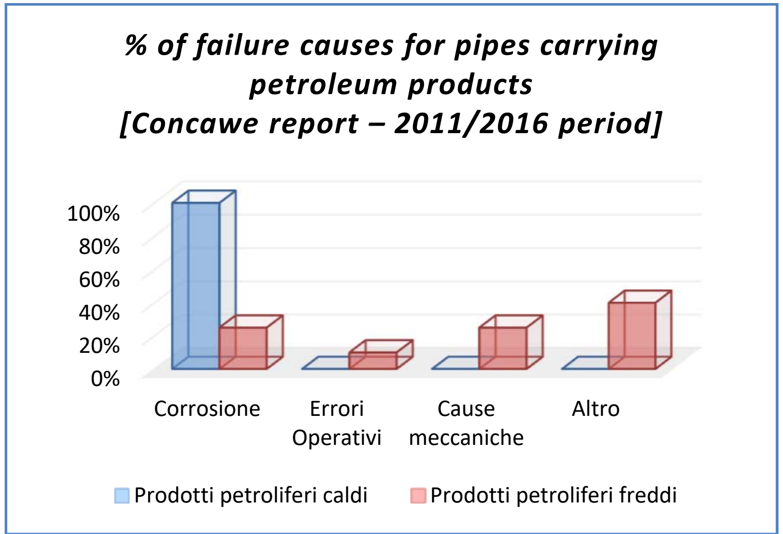
❑ **The guidelines suggest that failure frequencies indicated in the European Gas Pipeline Incident Data Group (EGIG) Report can be taken as a reference for natural gas pipes (buried or not buried, even within EST)**

✓ ***Report RIVM On-site natural gas piping - scenarios and failure frequencies (2011)***

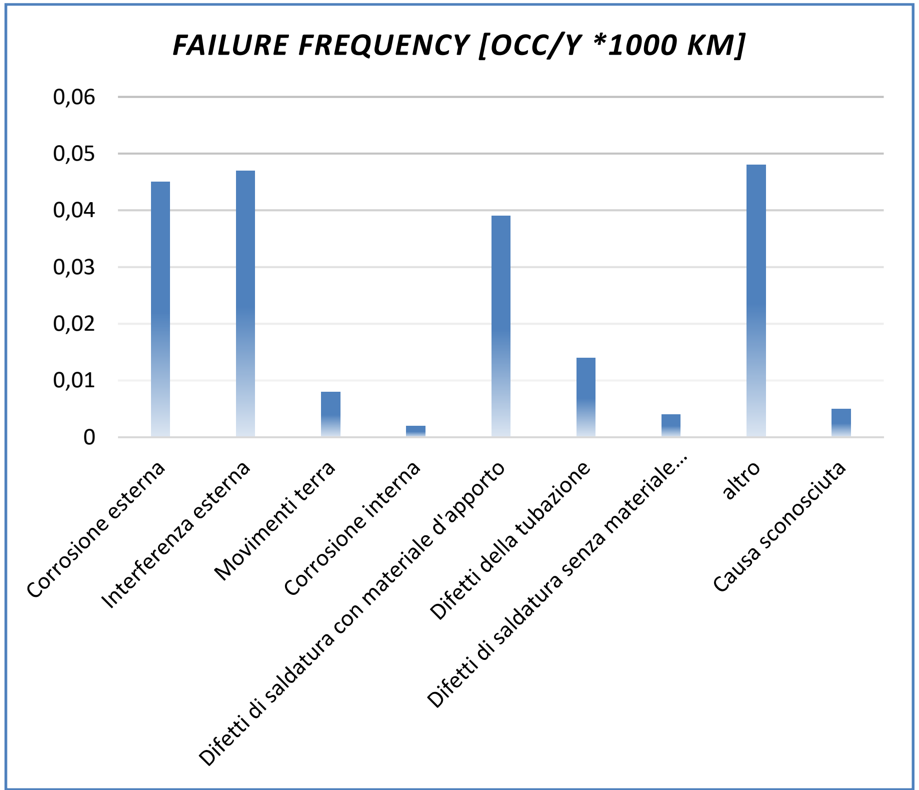
Risk analysis for surface plants

Incidence of the different failure causes on frequency

Data source	***Total rupture frequency (accidents/y*1000 km)***
UKOPA Report Pipelines of petroleum products in the UK during the period 1962-2016	0,212
CONCAWE Report Buried pipelines of petroleum products in EU during the period 1971-2016	0,46



Failure causes: corrosion, operational errors, mechanical causes



Failure causes: external corrosion, external interference, internal corrosion, welding defects, piping defects, other

Risk Analysis for surface plants

The API 581 standard: highlighted critical issues

- The API standard was developed by the American Petroleum Institute to define, implement and manage an inspection program based on risk analysis
  If this standard is used improperly and partially (Eg. taking into account in a generic way only of safety management system procedures) the results which 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 pipes failure.
- **The guidelines suggest**
  - ✓ **the use of methodologies for the drafting of a risk-based inspection plan such as the API 581: 2016 standard**
  - ✓ **if an inspection plan based on risk analysis has been prepared, its effectiveness in preparing an integrated analysis can be taken into account in order to reduce the frequency of accidents**

IMPORTANT: The reduction of occurrence frequencies through an integrated analysis that combines risk analysis with the safety management system allows the quantification of the positive effects of the system in order to prevent major accidents

Risk analysis for surface plants

The integrated approach to risk assessment

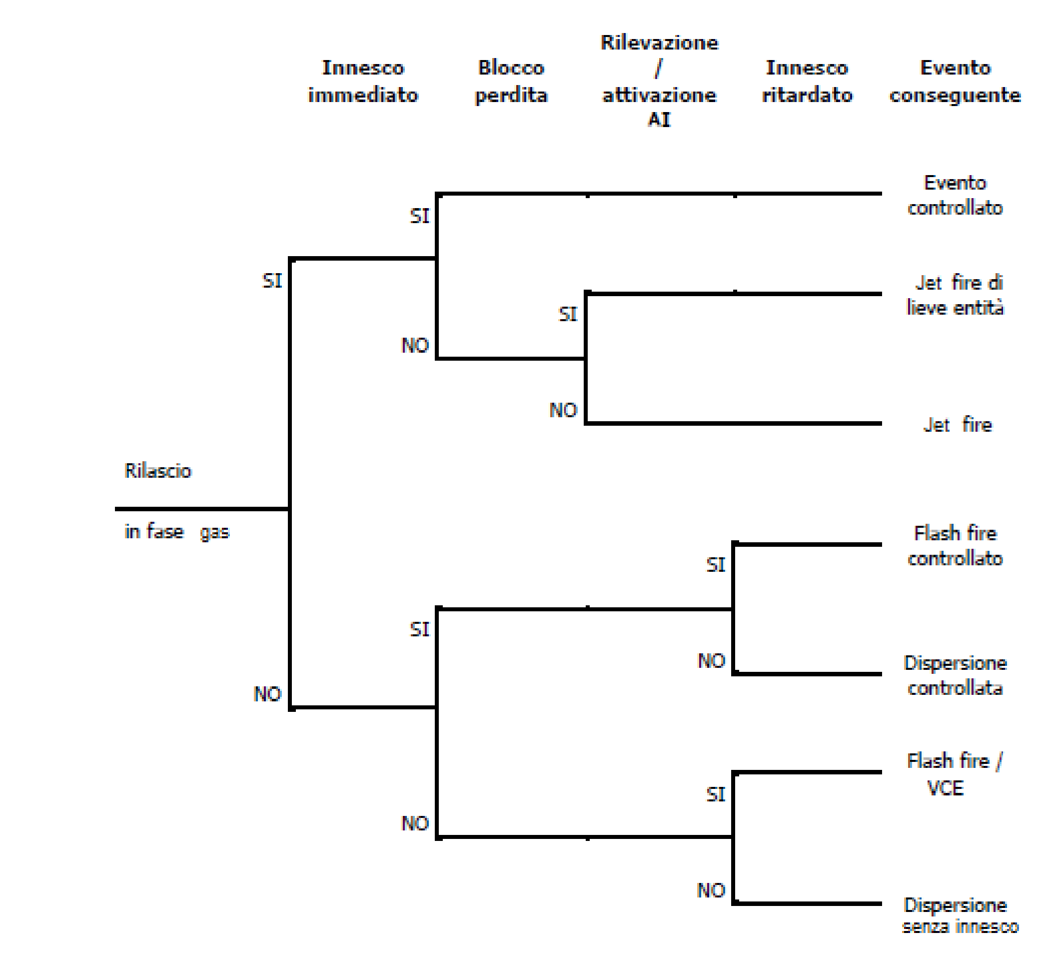
- **The guidelines describe the methodologies necessary for the integration of risk analysis techniques with benefits in terms of the reduction of the frequency of accidents deriving from the implementation of a safety management system (SMS)**
  - ✓ causes of failure, ways to prevent them and measures that can reduce the frequency of a particular cause and the subsequent total frequency

- ➢ “A quantified integrated technical and Management risk control and monitoring methodology” [EC Method (1999)]
  - ✓ It reduces the Top frequencies also for complex systems (Faul Tree Analysis)
- ➢ “The influence of Risk Prevention Measures on the Frequency of Failure of Piping” [International Journal of Performability Engineering (2010)]
  - ✓ Specific for random pipe failures

Eg. The Ukopa Report, the cause of main failure: external corrosion. The inspection plan aimed at this external corrosion reduces the frequency of pipe failure. The quantification of this reduction is obtained by applying the methods indicated above.

Risk analysis for surface plants

Evaluation of scenario frequencies (event tree)



Example of an event tree in case of fire safety systems and blocks

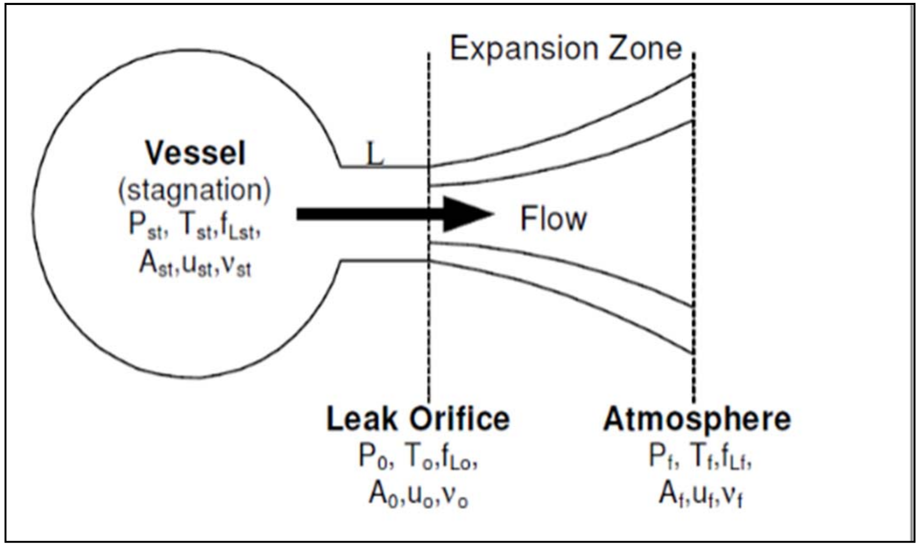
- **The guidelines highlight**
- ✓ **The trigger probability values to be reported in the event tree must be pertinent to the plant reality or cautiously estimated in favor of safety**
- ✓ **Methods for the calculation of the probability values of immediate/delayed triggering**

Ex: Purple Book 2005 "Guidelines for quantitative risk assessment" 2005; HSE 1997 "Ignition probability of flammable gas"

Risk analysis for surface plants

Calculation of consequences: physical phenomena of methane release

Modelling - High pressure methane release



Release phases of gas under pressure

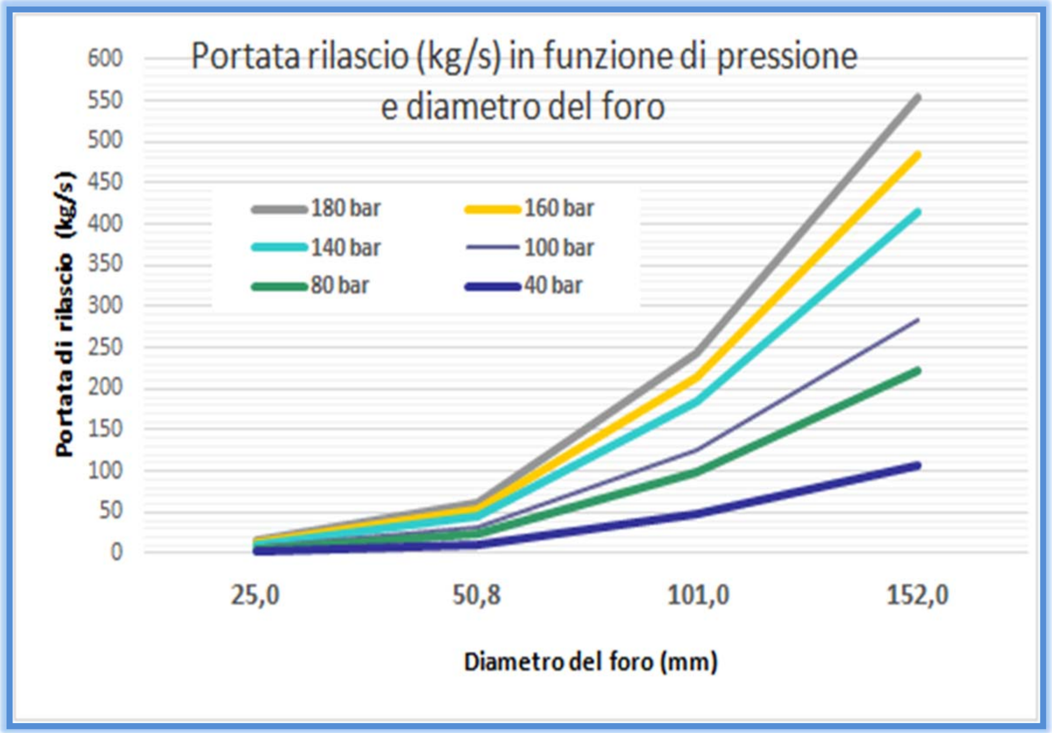
- ❑ **Phase 1: expansion from the initial pressure to the hole pressure**
- ❑ **Phase 2: expansion up to atmospheric pressure**
- ❑ **Phase 3: initial dilution**

Methane in supercritical conditions

- When a fluid is at a temperature and pressure higher than the critical ones it is in a supercritical state (no distinction between gaseous and liquid phase)
  - ✓ properties intermediate between those of a gas and a liquid and its density can be greater than that of gases in ordinary conditions

Risk analysis for surface plants

Calculation of consequences: gas density and release rate



Graph of the release mass flow rate as a function of the hole diameter for different pressure values in the range 40 -180 bar

✓ *The release flow rate varies according to the failure diameter and the pressure*

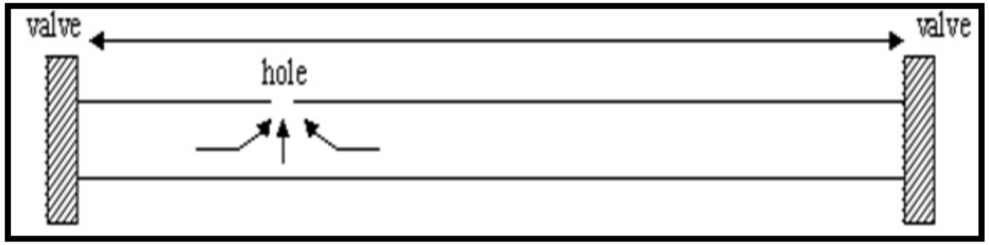
Release evaluation

- The density of methane proportionally affects the release rate
- The gas release rate must be calculated taking into account the gas density in supercritical conditions

Risk analysis for surface plants

Calculation of consequences: accident scenarios

- **Methane FLASH FIRE**
  - ✓ Fire of a flammable gas cloud that disperses into the atmosphere as a light neutral gas. The factors that affect modelling: density, weather conditions, release duration, cloud dilution, 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

- **The guidelines suggest that the intervention times assumed must be consistent with the emergency procedures and be verified by the working group with the plant personnel during field inspections**

Risk analysis for surface plants

Calculation of consequences: accident scenarios

- **A jet fire**
  - ✓ The release of a pressurized gas with immediate ignition and fire of a cloud. The factors that affect modelling: gas density, jet direction, release flow rate

- **The guidelines highlight that the jet fire damage areas identified are included within the damage areas for the corresponding flash fire scenarios. They must be considered especially for the purposes of evaluating a possible domino effect**

- **A Vapor Cloud Explosion (VCE)**
  - ✓ Confinement of the mass of flammable vapors 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/UFL

Conditions that facilitate the occurrence of a vapor cloud explosion are releases in areas with a high degree of confinement or in closed environments

Risk analysis for surface plants

Calculation of consequences: comparison of models (i.e. Phast®-DNV GL, Effects®-TNO)

- **The guidelines show how using a computational model that does not take into account the "super critical conditions" of methane**
  - ✓ **some software does not automatically take into account the initial expansion and dilution of the methane jet**
  - ✓ **It is therefore necessary to apply a dilution factor to the release range (approx 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 guidelines highlight that the verification of the models chosen for the estimation of the consequences must be adequate to the physical phenomenon reality**

Phast®-DNV GL	***Effects®-TNO***
It takes into account the initial dilution of the cloud due to the high speed and therefore to the release turbulence (methane super-critical conditions)	*The Gaussian dispersion model does not take into account the initial dilution of the gas and therefore gives more conservative results*

Risk analysis for surface plants

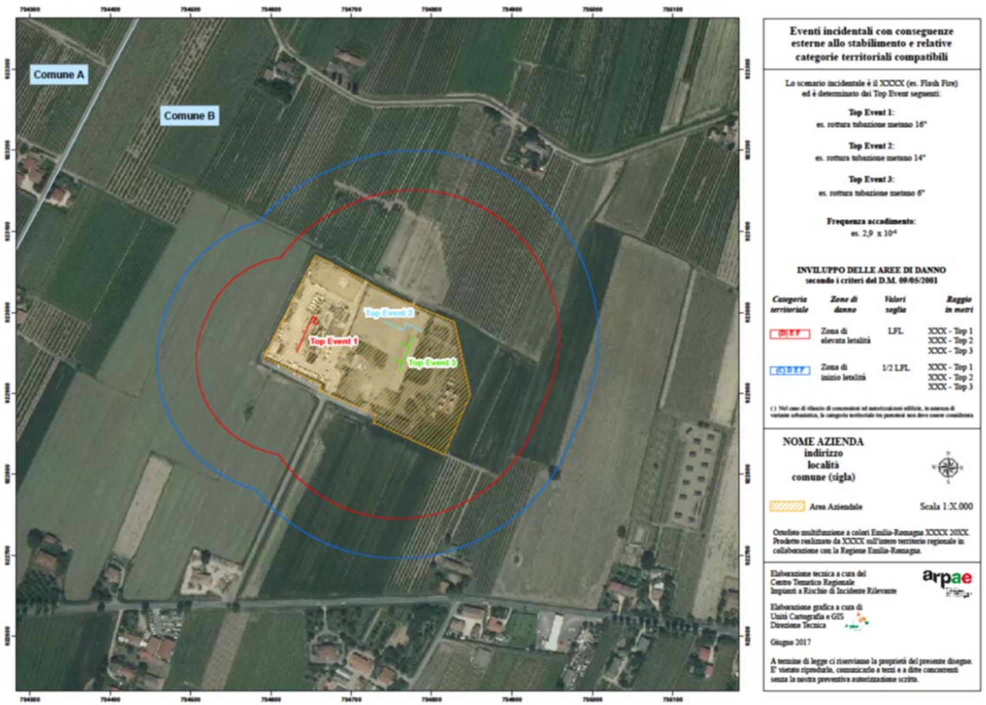
Safety systems

- **The Guidelines describe the main prevention and protection measures aimed at reducing the frequency and/or extent of the consequences of accident events**
  - 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 the single equipment is intercepted and stopped
  - Fire prevention measures and systems

Safety report evaluation conclusions

Example of external emergency planning

- **Flash fire: geo-referencing of the consequence evaluation**
  - ✓ *Top-event: failure of a natural gas pipe (152 mm hole) at an operating pressure of 140 bar*



FLASH FIRE – Damage Distances (m)			
Hole Diamter [mm]	**Pressure [bar]**	**Weather Conditions (D5)**	
		LFL	**½ LFL**
152	140	284.91	435.88

Weather conditions in the area: atmospheric stability class of Pasquill D5 (neutral) with wind speed of 5 m/s

Conclusions and further developments

Guideline Conclusions

The aims achieved by the guidelines in the evaluation of safety reports

1. The identification of the standards applicable to natural gas storage establishments and the respective areas of application and methods of coordination
2. The identification of specific individual safety aspects relating to reservoirs, surface plants and flow-lines
3. Criteria for choosing state of the art accident databases and sources of reliability data
4. Conditions of feasibility of the API 581 standard (RBI) in the risk analysis of safety reports
5. Conditions of use for commercial computational models for the study of the consequences for methane releases in super critical conditions
6. Uniformity of risk assessment throughout the national territory

Guideline Conclusions

Here are our indications to improve the national regulatory framework

1. Define a validated methodology of integrated risk analysis in order to quantify the effect of the safety management system and also establish the procedures which are necessary both to reduce the probability of occurrence and to reduce the extent of the consequences of major accidents
2. Identify credibility thresholds for accident events, as in other countries in Europe
3. Recognize ways to carry out Na-Tech risk analyses
4. Put in place measures to contain methane emissions (greenhouse gas) in conditions other than normal operation

Thanks for listening!

…questions?...

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