

## Safety of LNG Regasification Terminals: the Blue Book Approach

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The iNTeg-Risk research project (<http://www.integrisk.eu-vri.eu/>), carried out under the 7<sup>th</sup> Framework Program (EU Grant number CP-IP-213345-2), has the purpose to promote R&D activities aimed at the improvement of the management of emerging risks related to new materials and technologies. Within the project, a specific activity is dedicated to the development of innovative approaches for the assessment of safety of LNG terminals, both offshore and onshore. A specific Guideline ("Blue Book") was issued in order to summarize new developments and available data, methods and techniques for the assessment of LNG safety.

The present paper will focus on the specific contribution provided by Italian partners of the project to the "Blue Book". In particular, the work carried out on the assessment of specific scenarios related to LNG terminals and on consequence assessment models will be presented. A relevant effort was dedicated to the systematic exploration of credible accident scenarios that may follow external events involving LNG terminals. The results were used to consider the application of improved consequence assessment models both for the prediction of NG dispersion following release and for the Rapid Phase Transition that may be caused by massive LNG releases over water.

### 1. Introduction

The Integ-Risk research project (<http://www.integrisk.eu-vri.eu/>), carried out under the 7<sup>th</sup> Framework Program (EU Grant number CP-IP-213345-2), has the purpose to promote R&D activities aimed at the improvement of emerging risk management with specific reference to new materials and technologies. Within the project, an activity is dedicated to the development of innovative approaches for safety assessment of LNG terminals, both offshore and onshore.

Natural gas supply as LNG will play an increasing role in the European energy market, being expected to increase up to 70% in 2020. The number of regasification plants in Europe is going to increase, and new technologies for offshore terminals are finding an increasing application. New and emerging risks related to floating or off-shore installations are not fully explored to date and the hazards associated to these installations is highly perceived by the population. A specific Guideline (“Blue Book”) was thus issued, in order to summarize data, new developments, methods and techniques for the assessment of LNG safety gathered within the project. The present paper is focused on the specific contribution provided by Italian partners of the iNTeg-Risk project to the “Blue Book”. In particular, the work carried out on the assessment of specific scenarios related to LNG terminals and on updated consequence assessment models will be presented. A relevant effort was dedicated to the systematic exploration of credible accident scenarios that may follow external events involving LNG terminals. The results were used for the application of improved consequence assessment models both for the prediction of NG dispersion following release and for Rapid Phase Transition that may be caused by massive LNG releases over water.

## **2. Hazard Identification Techniques**

### **2.1 State of the art**

The analysis of the current state-of-the-art, as described by Technical Standards (e.g. CEN or NFPA), Safety Reports (for operative and proposed LNG terminals) and Technical Literature, reveals that quite conventional techniques are proposed in hazard identification for LNG terminals. These include hazard and operability studies (HAZOP), failure mode and effect analysis (FMEA), event tree methods (ETM), fault tree methods (FTM), etc. Thus, no specific method was identified. Moreover, the analysis of the current state-of-the-art in hazard identification for LNG plants evidenced the presence of gaps and “grey areas”. The key issues identified in gap analysis concerned the availability of a guided approach to the systematic extension of the consolidated knowledge to innovative design solutions, the assessment of external threats, and the inclusion of “unknown known” hazards from the analysis of past accidents and near-misses.

A portfolio of improved hazard identification methods was thus developed to bridge the gaps in the application of hazard identification techniques to LNG terminal technologies. The proposed methods represent mostly improvements and integrations of traditional tools, specifically developed to address specific gaps identified.

### **2.2 Dynamic Procedure of Atypical Scenarios Identification (DyPASI)**

The Dynamic Procedure for Atypical Scenarios Identification (DyPASI) consists in a self-learning method for the systematization of information from past accidents and near-misses and the generation of bow-tie branches, consistently with the methodologies developed in the ARAMIS Project (Aramis, 2004).

DyPASI can be applied to the identification of atypical hazards related to the safety of new and alternative technologies for LNG regasification. A hazard can be classified as “atypical” when it cannot be captured by common hazard identification techniques

because deviating from normal expectations. The aim of DyPASI is to make easier and systematic the inclusion of atypical incident scenarios in “hazard identification” processes, which are often unable to capture low probability events or events for which limited knowledge exists. The method is based on a general horizon screening, which can make aware of potential hazards and incident scenarios related to substances, equipments and industrial process considered. The main goal is to identify the specific accidental chains and to infer general accidental patterns. A more detailed description of this methodology can be found elsewhere (Paltrinieri et al., 2010).

Table 1: DyPasi procedure steps

Steps	Bow-tie diagram generation (Delvosalle et al., 2006)	Dypasi procedure
0	\	Pre-analysis aiming at the identification of potential atypical incident scenarios and at the creation of proper diagram branches describing related bow ties.
1	Drawing up a list of hazardous substances present in the plant	This step allows the evaluation of additional hazards of substances, not described by risk phrases but defined in the pre-analysis
2	Definition of critical events	The purpose of this step is to include the critical events outlined in the pre-analysis or to identify them among those proposed by MIMAH.
3	Construction of event trees	This step allows the inclusion of critical event consequences previously considered or their identification by the event trees obtained by MIMAH, on the basis of what outlined in the pre-analysis.
4	Construction of fault trees	This step allows the inclusion of the cut-set of the critical events previously considered or their identification in the fault trees obtained by MIMAH, on the basis of what outlined in the pre-analysis.
5	Definition of safety barriers	Once defined bow-tie diagrams, safety barriers are studied. This step aims at the identification of the existing safety barriers and at the definition of new useful safety barriers.

Thus, DyPASI is a procedure able to consider early warnings concerning atypical incident scenarios coming from past incidents, inherent studies or general concern. This procedure was developed to support the bow-tie diagrams MIMAH methodology and should be applied only once general MIMAH bow-tie diagrams for the case being studied were built. The procedure allows also a double check of the hazard identification process.

An atypical incident scenario is the result of a sequence of events, not necessarily all atypical. Thus, in order to properly describe an atypical incident scenario, both atypical and non-atypical events should be added or identified, step by step, in the process of bow-tie construction. Table 1 shows all the steps of the procedure and relates them to the corresponding MIMAH phases of diagram generation. Figure 1 shows a chain of

events identified by the DyPASI procedure. The data in the figure allow the integration of the RPT scenario in the bow-tie diagrams developed using the MIMAH procedure.

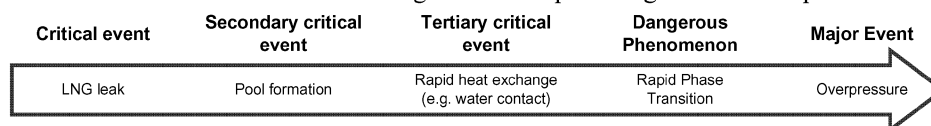


Figure 1: Example of chain of events leading to Rapid Phase Transition explosion

The DyPASI procedure allowed the inclusion of atypical incident scenarios in hazard identification processes by a systematic procedure. Moreover, specific atypical incident scenarios that otherwise would not captured by common hazard identification techniques were detected. Finally the procedure also allowed a double check of the hazard identification process carried out using MIMAH, in order to determine if all the incident scenarios were described.

### 2.3 HazId for external threats

HazId is a structured review technique based on brainstorming sessions. Although its guidewords are in part standardized (e.g. in ISO 17776) HazId relies mainly on the HazId leader and team experience to ensure a complete identification of threats during the brainstorming meetings. The guidewords usually adopted are detailed for what concerns “internal” or “intrinsic” hazards, but are left to a more general level of detail for what concerns hazards deriving from external actions or conditions. Within the Integ-Risk project, specific HazId sessions were dedicated to develop a list of guidewords and to identify a list of threats specifically dedicated to the identification of external threats for LNG regasification terminals. The brainstorming was carried out by an extended group of experts. An example of results is reported in table 2.

Table 2: Specific external threats identified for LNG terminals

HazId Guideword	Threat (Hazard) Offshore	Threat (Hazard) Onshore
<b>Man Made</b>	Direct attack Third Party activity Dropped object Helicopter operation Human Factors	Direct attack Third Party activity - - Human Factors

## 3. Models for Consequence Assessment

### 3.1 Rapid Phase Transition explosion

Rapid Phase Transition can be the only cause of explosion if ignition does not occur after the accidental release of LNG on water. However, a high level of uncertainty is related to the modeling of this phenomenon. Many models have been put forward in the literature, each of them addressing specific aspects of the phenomenon, but none of them is capable of properly representing all the parameters involved. This is due both to the complexity of the phenomenology of the accident, and to the many different routes

the accident can follow (scenarios), which are difficult to be predicted. Moreover, the scarce experimental data available do not provide useful insights on the phenomenon, sometimes providing conflicting information.

Assuming the occurrence of an explosion, if the calculation of the pressure profile is taken into consideration, only the classic TNT equivalency method was used for the estimation of the pressure profile as a function of the distance from the location of the release. However, significant physical differences exist for the two typologies of explosion. Starting from these considerations, a new approach was recently suggested, based on the use of the gas-dynamic similarity, by using acoustic model (Bubbico and Salzano, 2009). This approach has already provided interesting results in the study of the BLEVE explosion. However, important uncertainties in the quantification of the release rate, the mixing effect with water and the evaporation rate must be preliminarily solved in order to obtain a significant improvement in RPT modeling.

The acoustic evaluation of the pressure wave produced by a RPT of LNG released accidentally on water validated the safety distances reported by Sandia National Laboratory, which has revisited LNG hazards focused on spills from ships onto water based on experiments. Significant impacts of a RPT of LNG on public safety and property are expected only for very large release rates ( $> 100 \text{ m}^3 \text{ min}^{-1}$ ) and are limited to distances lower than approximately 250m from the accidental spill source. This value may increase up to about 500m in the case of spills induced by “intentional” releases.

### **3.2 Best Available Model selection for Heavy Gas Dispersion**

Among the potential consequences of LNG loss of containment in LNG regasification terminals, the formation and dispersion of flammable clouds has a particular relevance. In open field dispersions both integral models and CFD tools give accurate predictions. Thus, since CFD codes require a larger amount of resources, integral models should be preferred to obtain results in a relatively short time. When geometric complexity grows slightly CFD maintains good performances, while accuracy of integral models begin to fade; nevertheless, integral models should be still considered suitable for engineering purposes, and consequently still preferred. However, releases involving large obstacles have to be simulated by using a CFD approach in order to obtain accurate predictions.

Therefore, a general methodology to discriminate between CFD and integral models for risk assessment of scenarios involving obstacles would be very useful. Missing such a methodology can lead to inaccurate predictions and, consequently, inadequate mitigation systems (underestimation of the cloud size due to the use of integral models on geometrical complex scenarios), or waste of resources (application of CFD to simple geometries, where integral models grant good results). Consequently a parametric analysis was performed, and differences between gas cloud size in open field and in presence of an obstacle were studied. A case study was considered assuming a steady state release of an inherently heavy gas (namely  $\text{SO}_2$ ) in an open field presenting an obstacle located downwind of the release point. Parameters analyzed were the obstacle geometry and position. Influence of stability classes have also been studied: simulations were carried out both in neutral stratification, with a  $5 \text{ m s}^{-1}$  wind (5D) and a very stable stratification, with a  $2 \text{ m s}^{-1}$  wind (2F), which are the most commonly used atmospheric conditions for risk assessment. A standard procedure for mesh generation has been

applied, imposing 0.1cm triangular elements on the obstacle and applying a size function with growth factor 1.1 and size limit of 5m. Mesh independence has been checked using halved size elements for a reference case defined for each stability class. Dimensionless parameters were defined in order to make data obtained in different simulations comparable. Simulations were performed with two series of obstacles, changing the value of the parameters. The results clearly pointed out that integral models are inaccurate when large obstacles are involved. The adimensional parameters defined were capable to define a region where such models are highly inaccurate depending on the geometry of obstacles. Thus, a procedure was defined for a first screening of the scenarios that require the use of CFD tools to obtain reliable predictions of cloud dispersion.

#### **4. Conclusion**

An important effort was dedicated within the iNTeg-Risk project to develop guidelines for the assessment of scenarios related to accidents in LNG regasification terminals. Relevant results were obtained both in the development of improved specific hazard identification techniques and in the identification, further development and assessment of best available models for consequence analysis.

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