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Explosion Risk Analysis ‘ERA’ for FLNG Facilities: the Main Challenges

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Floating liquefied natural gas facilities (FLNG) have the potential to revolutionize the way natural gas resources are developed by moving the production and processing out to sea. This is a major innovation that brings huge new energy resources within reach, but the high potential risks and the novelty of the concept require detailed and sometimes new safety studies. Fire and Explosion risk analysis, Cryogenic risk analysis, Smoke and gas dispersion risk analysis, etc. feed into a Quantitative Risk Assessment (QRA). Performing these safety studies is challenging, given the lack of any feedback and references.
Among all the safety studies, this paper focuses on the Explosion Risk Analysis (ERA) since major design inputs are derived from this study e.g. overpressure Design Accidental Loads (DAL) for Safety Critical Elements. It is of primary importance to ensure robustness of its study basis, assumptions and approach.

1. Introduction

Natural gas is the most energy-efficient fossil fuel; it offers important energy-saving benefits when it is used instead of oil or coal. Its popularity as an energy source is expected to grow substantially in the future because natural gas can help achieve two important energy goals for the twenty-first century: providing sustainable energy supplies and services needed for social and economic development and reducing adverse impacts on global climate and the environment in general.
Floating liquefied natural gas facilities (FLNG) have the potential to revolutionize the way natural gas resources are developed. Moving the production and processing out to sea where the gas is found is a major innovation that brings huge new energy resources within reach. It also avoids the potential risk to life and health to neighbouring communities, the environmental impact and land use issues linked with constructing and operating a plant onshore, including laying pipelines to shore and building other infrastructure. FLNGs will be the largest floating offshore installations in the world (largest planned facilities will have decks having the length of more than four soccer fields), they will typically be one-quarter the size of an equivalent onshore plant limiting the space available for implantation of Process equipment within the Topsides; available space within the substructure being mainly dedicated to storage tanks and the specific marine equipment.
There are many major safety issues associated with the development of this new kind of facilities. The potential risks due to processing of hazardous materials (flammable liquid and gas, cryogenic liquid, toxic and asphyxiating gas, etc.) are worse and magnified due to the proximity of a gas liquefaction plant and living quarters. This context creates a need for particularly detailed safety studies (e.g. Fire and Explosion risk analysis, Cryogenic risk analysis, Smoke and gas dispersion risk analysis, etc.) as inputs to a Quantitative Risk Assessment (QRA). The main objective of these safety studies is to demonstrate that the installation is designed so that people will be able to escape safely in case of a major incident (lesson learned from Piper Alpha disaster). The proper design of Escape Evacuation and Rescue (EER) systems must be validated. Identified risks must be reduced to levels “As Low As Reasonably Practicable” (ALARP) by implementing all necessary safety barriers (preventive and recovery) in the early stages of the FLNG project. Needless to say these safety studies are challenging given the novelty of FLNG as a concept.

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Among all the safety studies, the present paper focuses on the Explosion Risk Analysis (ERA) since major inputs for design are derived from ERA studies e.g. overpressure Design Accidental Loads for Safety Critical Elements, it is therefore of primary importance to ensure robustness of its study basis, assumptions and approach.

2. Overview of the Explosion Risk Analysis methodology

It is not our intent here to provide a full description of the typical Explosion Risk Analysis methodology which has been extensively described in the literature (e.g. Vinnem, 2011). Nevertheless a brief overview of overall ERA methodology is a useful support to our discussion hence we will focus on the main steps of the Explosion risk analysis. Similarly, it is emphasized that our paper is limited to offshore facilities for which there is a need to assess complex behaviours (accounting for complex geometry and obstacles). Therefore, Computational Fluid Dynamics (CFD) dispersion and explosion modelling tools are increasingly used.
In a typical ERA, a statistical analysis of occurrence of all aspects of the event sequence leading up to an explosion is required, in order to establish a probabilistic representation of the blast loads. This will include the following aspects:

- leak frequency analysis
- flammable gas dispersion
- ignition probability modelling
- flammable gas explosion

The flowchart provided in Figure 1 shows how the different tasks interrelate.

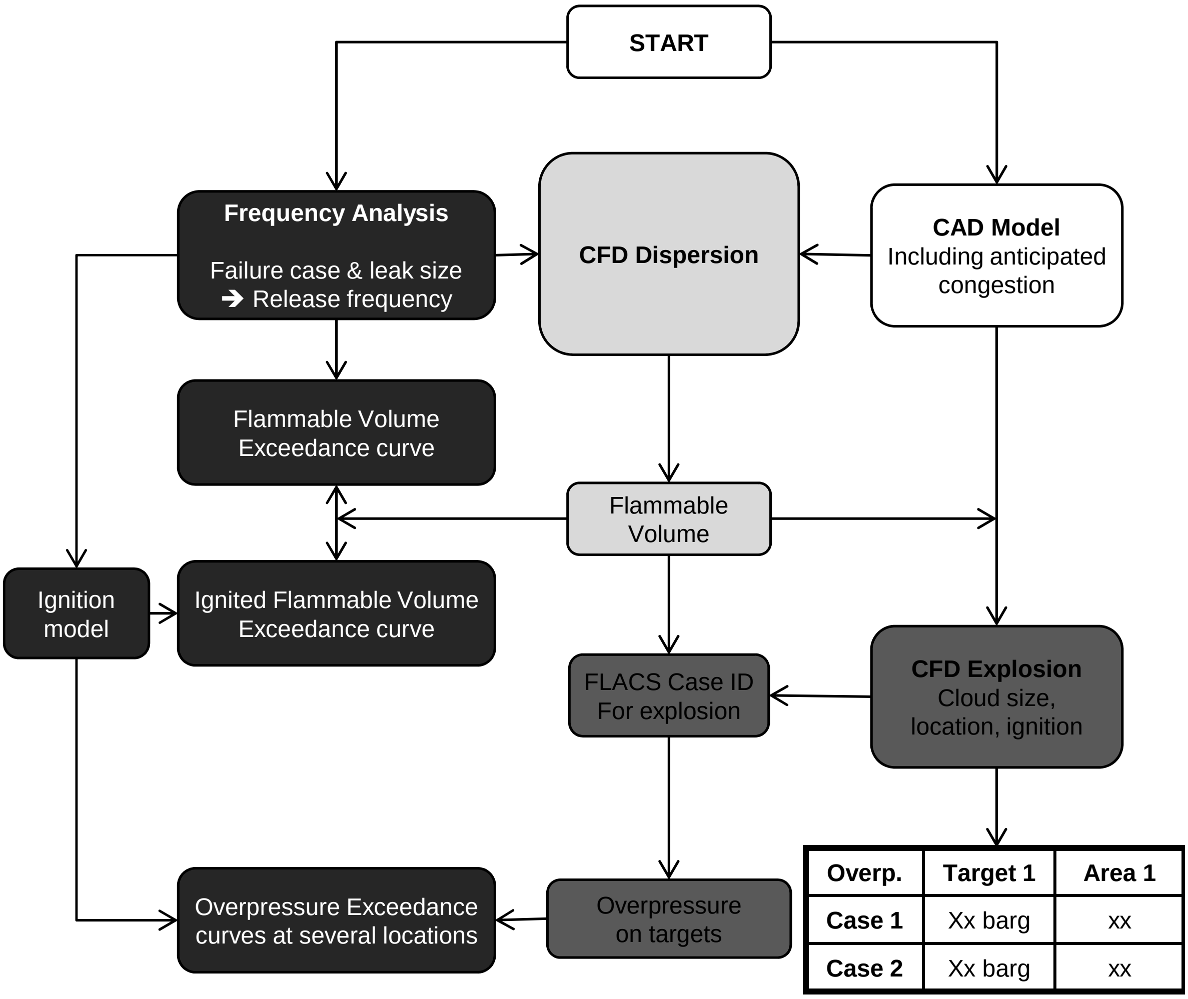

Figure 1: Explosion Risk Analysis typical flowchart

2.1 Frequency assessment

Since the ERA is a risk based approach it is not limited to a single worst case nor a limited number of credible scenarios but it considers all the potential losses of containment (e.g. small, medium, large and even full bore leak) that can arise in the facility and attributes a probability to each event. The likelihood of loss of containment of a given isolatable section of the process is determined using historical failure rate data for standard plant components (e.g. pumps, valves, flanges, etc.). The frequency assessment involves the quantification of failure frequencies by combining the component failure rate data with a component 'parts count' of a given isolatable section. This parts count is done for all the isolatable sections that have been identified in order to cover the risks of the entire facility. This frequency assessment is the first step of any risk based approach. The HSE hydrocarbon release database (HCRD) has become the standard source of release frequencies for offshore facilities (OGP, 2010).

2.2 CFD dispersion modelling

Since an offshore facility is a very complex environment the use of a simple dispersion model is not appropriate to assess the development of a flammable gas cloud in such a congested and obstructed environment. Instead, several CFD dispersion tools (CFX, FLACS, STAR-CD …) are available and their use is nowadays considered as standard offshore industry practice. However, there are many parameters (e.g. location of the leak source, direction of the gas jet, flow rate of leak, wind direction and speed, etc.) that need to be considered as input to the CFD simulation model. Permutations may result in a large number of simulations to be performed.

Typical output from a dispersion model is the flammable volume of the clouds shown in Figure 2.

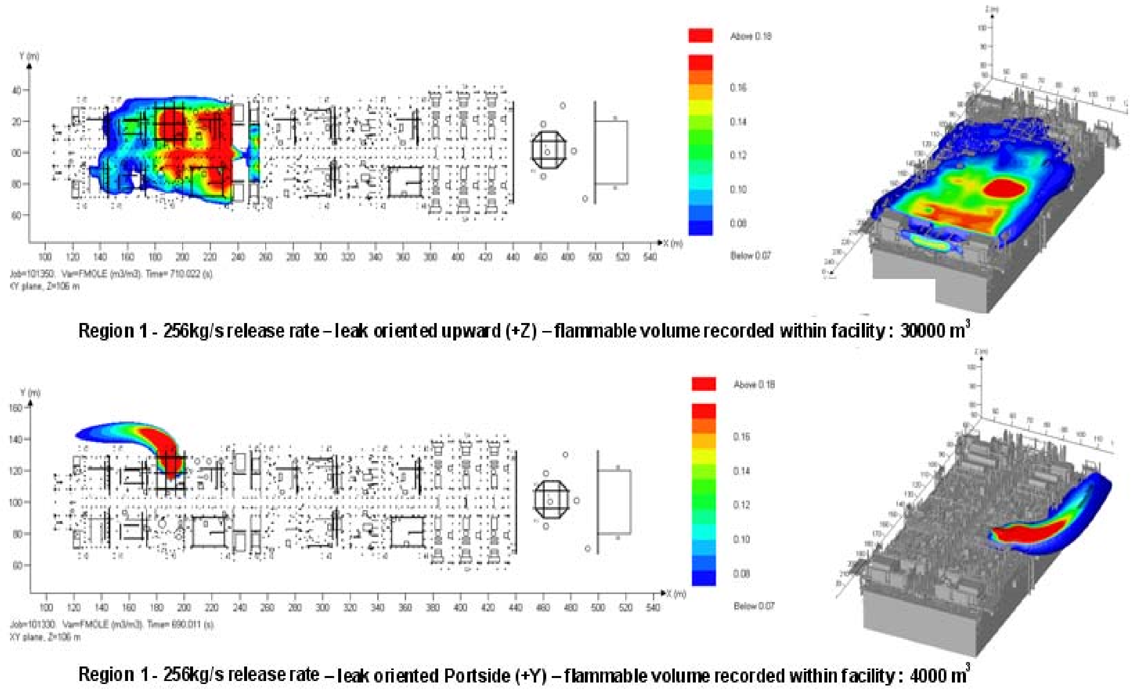

Figure 2: Flammable cloud developing within the topsides of an offshore floating facility

2.3 CFD explosion modelling

Dispersion modelling will define a range of flammable clouds that can be formed in different areas of the facility. In the event of delayed ignition, this will result in a gas explosion. The effects of an explosion will depend on the maximum pressure, duration of the shock wave and interaction with structures, etc. These values must be determined by model that takes into account a number of variables as (Lea and Ledin, 2002):

- Fuel type (reactivity of fuel)
- Stoichiometry of fuel
- Ignition source type and location

- Confinement and venting (location and size)
- Initial turbulence level in the cloud
- Blockage ratios
- Size, shape and location of obstacles
- Number of obstacles (for a given blockage ratio)
- Could size

Empirical models such as the TNT equivalency model, the multi energy concept (Van den Berg, 1985), etc. do not consider these variables. Therefore, as for dispersion, the answer is one or other of the commercially available CFD explosion tools (AUTOREAGAS, FLACS, CFX …) are their use is nowadays considered as standard offshore industry practice.

2.4 CAD Model of the facility

In order to produce an accurate assessment, both CFD dispersion and explosion modelling require having a detailed 3-D CAD model of the facility as an input for the calculations.

The level of detail and completeness of the CAD model was shown to be a very important parameter in determining the overpressure. Figure 3 (UK HSE, 1998) shows the rise in peak over-pressure as the amount of piping congestion is increased, for a typical North Sea offshore platform.

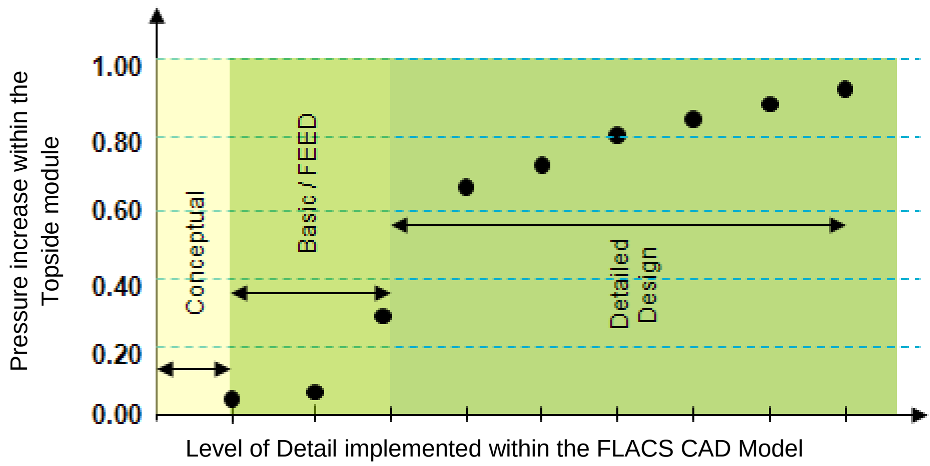

Figure 3: influence of geometry details on maximum overpressure figures

This demonstrates the importance of having a detailed geometry description in the explosion model (including pipework down to diameter of 2’’) to avoid underestimating the overpressure design accidental loads.

3. Specificities of Floating LNG facilities

The first and maybe the most important specificity of the FLNG facilities is that though there are two on-going Engineering, Procurement, Construction and Installation (EPCI) Projects in the world, there are no existing facilities to serve as a reference.

Then, though it may look quite similar at first sight, an FLNG is significantly different to an oil FPSO. Indeed, an FLNG is actually a gas processing plant hence pipe diameters tend to be larger and almost any accidental release will result in a flammable gas cloud. On the other hand the potential for pool fires is limited.

FLNGs will be the biggest floating man-made objects ever with typical dimensions ranging from circa 350 m to 490 m long and 60 m to 75 m wide.

Each FLNG layout is unique and influenced by many factors like the relative location of the living quarters, the flare and the turret, the choice of a side by side or tandem offloading system, the presence of safety gaps and/or fire and blast walls, the choice of liquefaction process (nitrogen or dual mixed refrigerant for instance) and the design preferences and standards of the operator.

The combination of the above means that application of the established industry codes and standards for the development of an FLNG facility is a challenge since codes such as ISO 13702:1999 or API RP 2 FB:2006 have been developed and improved based on feedback from very different installations.

4. Main challenges in performing an ERA for FLNG facility

Technip has performed many FLNG studies over the last 5 years at all project stages – conceptual Design, Front End Engineering Design and EPIC. The main challenges that had to be overcome in performing ERA studies for these projects are described in the following lines.

4.1 Detailed CAD model of the facility

As outlined in section 2.4, it is of primary importance to have a detailed 3-D CAD model to predict accurate dispersion and explosion results but who knows what an FLNG process module looks like when there are no as built references to date? In this context, and given the iterative nature of design, developing a geometric model that is sufficiently detailed to start the studies has required ‘educated guesses’.

Technip’s combined recent experience on many LNG and FPSO projects allowed the organization of multi-disciplinary workshops between Piping/Layout, Process, Structure, Instrumentation and HSE Design engineers and experts. Working in this way made it possible to minimize the uncertainties and to improve the degree of confidence in the CAD model that is used to perform the dispersion and explosion simulations.

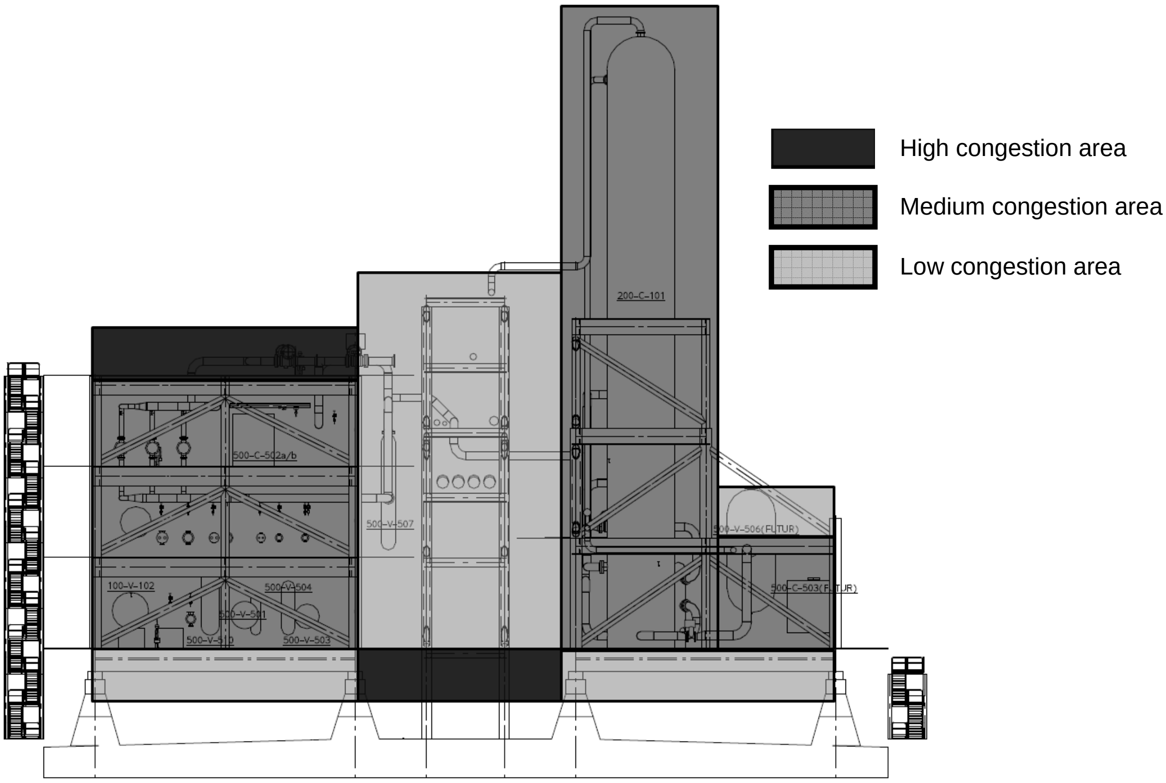

Figure 4: identification of requirement for so-called anticipated congestion

The main outcomes of these workshops are sketches like the one shown in Figure 4 classifying open volumes in terms of anticipated congestion. Indeed, at the early stages of design or when the model is incomplete, small diameter pipework, cable trays, junction boxes, piping supports etc. are not included. To adjust the model to improve the accuracy of blast wave progression, the density of pipe arrays can be increased to reflect what we refer to as “anticipated congestion”. Such anticipated congestion methods (Hoorelbeke et al., 2006) are widely used in blast studies and have been used by Technip on past offshores projects (Platforms, FPSOs, etc.) and more recently for FLNG projects.

4.2 Modelling and computational issues

There are also many modelling and computational issues that need to be overcome. The main concerns are briefly described below.

As described in section 2.2 and 2.3, numerous CFD dispersion and explosion calculations (i.e. several hundreds of dispersion and explosion simulations) have to be carried out on an FLNG project to provide sufficient information about flammable gas dispersion within the topsides as well as the magnitude of the overpressure in the event of subsequent ignition. The amount of data produced by the CFD tools must be

sufficiently detailed to derive realistic design overpressures and accidental loads. Performing all these calculations within a timeframe compatible with the project schedule is a real challenge. This time constraint is exacerbated by the fact that the computational domain is very large (due to the size of the facility) leading to long calculation times e.g. the duration of a single dispersion scenario using FLACS over a large computational domain can typically last for 1.5 d even on most up to date computers.
Finally, there are also several challenges in terms of modelling assumptions to be considered in the analysis, especially concerning frequency. Indeed, contrary to other offshore installations, there is obviously no historical data for leakage frequency available specifically for FLNG's. The same remark applies to ignition models for which no specific FLNG development is available.
To deal with this specific assumptions for FLNG ERA studies have been defined by HSE Design engineers and cross-checked using input from Technip's engineering disciplines, partners and equipment vendors.

5. Conclusion

There are many challenges to take up in order to properly perform an Explosion Risk Analysis for an FLNG facility. Despite all the challenges, Technip developed a robust methodology for performance of ERA study by merging know-how of Technip engineers and experts gained from past experiences in both onshore large LNG projects and offshore projects such as FPSOs. So far, Technip completed ERA studies on several Conceptual, FEED and EPC FLNG projects.
Those developments are of primary importance since the overpressure Design Accidental Loads specifying the overpressure figures for designing the Safety Critical Element (such as large vessels containing hydrocarbons, primary structure, Emergency shutdown valves, etc.) are typically derived from the ERA study. The detailed approach developed by Technip for the FLNG developments ensures provision of a robust design against explosion (and more generally against all the Major Accident Events) aiming at preserving the integrity of the floater until evacuation is completed.
Through those achievements on recent real projects, Technip demonstrated its ability, either to specify and manage work by a third party or to perform ERA studies in-house. Most of the ERA studies performed on Technip's projects are subcontracted to specialized consultancy companies but Technip has also its own risk assessment tools and databases for anticipated congestion and leakage frequency, that now include the finalized design of real FLNG projects. To date, Technip has the capability to perform in-house ERA studies for complex offshore facilities. This execution scheme provides the flexibility to anticipate design modification and changes in the project's schedule and thereby better protect the design, project schedule and support our clients.
Integrated team of Engineer encompassing representatives from Technip and its partners as well as client successfully produced in 2010 in Paris the world's first ERA for a real FLNG facility and one year later, Technip Paris team completed its first in-house ERA meeting the project schedule and fulfilling client expectations.

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