EVOLCODE: LAST EVOLUTION FOR THE CALCULATIONS OF CONSEQUENCES OF LNG RELEASES AND LNG FIRES

V.Blanchetière
Research engineer
GDF SUEZ
Saint-Denis La Plaine, France
vincent.blanchetiere@gdfsuez.com

ABSTRACT

The raise of societal sensitivity regarding plant safety combined with the recent regulators demand is new challenges for the gas industry and for GDF SUEZ in particular. Even if GDF SUEZ has been involved in the main partnerships to understand and model phenomena associated to LNG accidental releases, new developments are necessary. Those developments, performed in partnerships, concern flashing jets, interaction pool spreading and LNG pool fires.

Thus, GDF SUEZ has developed many high-performance and easy-to-use tools over the past twenty years, to quantify the risks and consequences of accidental discharges of natural gas or LNG at all points of the natural gas chain. Among them, EVOLCODE is used for the safety studies carried out for its LNG terminals. It was specifically developed to predict the consequences of accidental LNG releases. It is composed of several models directly based on the fluid mechanics and combustion or on semi-empirical formulations. EVOLCODE includes last knowledge in phenomena modeling.

Those models have been largely validated through laboratory and field tests, up to real scale experiments carried out in the framework of international partnerships, particularly, LNG pool fires of 35 m diameter in Montoir de Bretagne (largest LNG pool fire tests). The high validation of the software, based on the new developments, will be continuously reinforced.

INTRODUCTION

Risk assessment for LNG facilities

The LNG industry continuously handles easy flammable and very energetic mixtures, that's why hazards due to accidental releases is a common concern. The first development of LNG facilities was marked by the lack of knowledge on cryogenic conditions which results in the Cleveland accident in 1946. Since this period, knowledge and technology strongly evolved and accidents became very rare. However, safety is still a priority for LNG terminals, peak-shaving units and liquefaction plants.

On the other hand, accidents in other industries have raised the societal sensitivity regarding safety. For example, the incidents in the fuel depot of Buncefield (UK, 2005) and in the agrochemical plant of Toulouse (France, 2001) have produced impressive damages and the images have chocked the civil society. After these incidents, the authorities have reacted by a reinforcement of rules applicable to all industries, especially for the risk assessment.

The risk assessment is a key point to improve the safety of workers and population around facilities. The risk is commonly defined as the combination of the frequency of accidental releases and the gravity of these events. Feedback analysis and statistical methods provide data to quantify the leak frequencies for the different LNG equipments whereas, it is more difficult to predict the consequences of the releases. It depends of numerous parameters related to the origins of the spill (hole size, pressure, temperature,…) and the environment (wind speed, air humidity,…). It also involves complex phenomena such as gas dispersion, thermic exchanges and combustion.

The risk assessment needs tools to describe the hazardous phenomena and to quantify the consequences whatever the conditions of the spill.

EVOLCODE: a solution to calculate the consequences of LNG releases and LNG fires

GDF SUEZ has been involved in the main partnerships to understand and model phenomena associated to LNG accidental releases. Thanks to these partnerships, GDF SUEZ has developed many high-performance and easy-to-use tools over the past twenty years, to quantify the risks and consequences of accidental discharges of natural gas or LNG at all points of the natural gas chain. Among them, EVOLCODE is already used for the safety studies carried out for some LNG terminals.

EVOLCODE was specifically developed to predict the consequences of accidental LNG releases. It is composed of several models directly based on the fluid mechanics and combustion or on semi-empirical formulations. EVOLCODE includes last knowledge in phenomena modeling.

EVOLCODE is a suite of modules which enable to model the different steps in a accidental release (Figure 2). The module called "FUITE" calculates the mass flow rate and the characteristics of the release (temperature, droplet size, velocity,…). The module called "EVANUM" predicts the pool extension and vaporization on different surfaces (concrete, sand, water,…). The module called "EOLE" models the gas dispersion from a LNG pool or from a jet to evaluate the flammable cloud extension. The module called "CORE" calculates the heat radiation produced by a pool fire and can predict the efficiency of extinction system (foam).

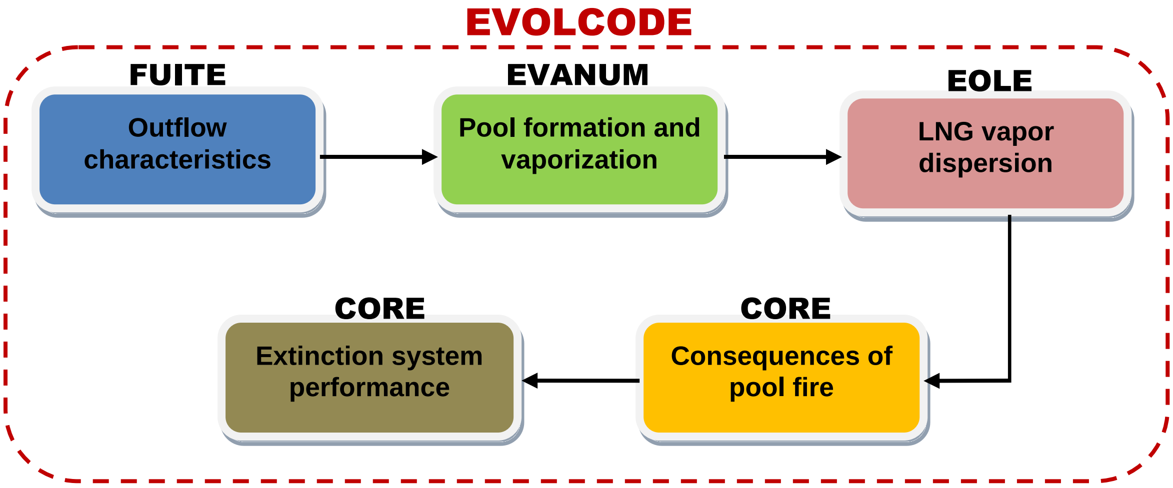

Figure 2: EVOLCODE structures – different modules for the different phases of LNG releases and LNG fires

EVOLCODE can consider different mixtures of LNG or other liquefied gases, which properties (composition, thermodynamics constants,…) are defined in a database used by the different modules. The module EVANUM and CORE use other databases on different types of soils to calculate the pool extension and different types of facilities to calculate the heat radiation received by the structures.

EVOLCODE is quick and simple to use thanks to an user-friendly interface, compatible with Windows Vista and previous systems. The user only has to choose the hypothesis on the leak and its environment. No parameter on models is accessible in order to ensure the consistency of results with different users.

THE "FUITE" MODULE: FLOW RATE CALCULATION FOR LNG RELEASES

Description of functions and theory

The FUITE module gathers several models to calculate the flow rate from different scenarios of leak in a LNG site:

- Pressurized release through punctures in pressurized LNG reservoirs (tank or pipeline),
- Gravity based discharge from spherical or cylindrical tanks (vertical or horizontal),
- Rupture of horizontal or inclined pipes (with or without a pump in downstream).

The FUITE module calculates the evolution of the release rate against time, in considering the pressure and inventory decreases. It also provides information on the flash of liquid (droplet size, vaporization rate at the orifice, …) which are necessary to model the pool spread and the gas dispersion (Figure 3).

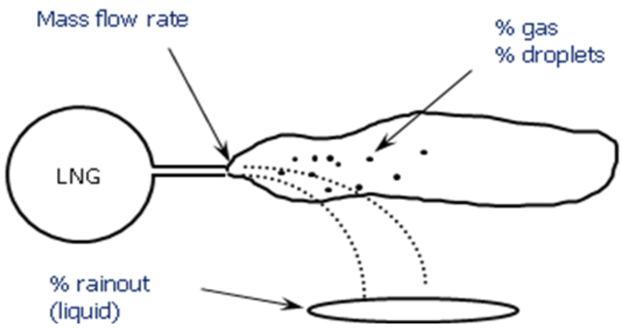

Figure 3: the FUITE module calculates the release characteristics that will be used by the others modules

The theoretical models includes the equilibrium equations (liquid saturation), the simple Bernoulli equations and semi-empirical formulas to characterize the flash of liquids. These equations enable to describe the complex behavior of a LNG release. For example, in case of the full-bore rupture of a long pipeline, FUITE solves the transient release by considering three steps:

- Step 1: The temperature is constant and the pressure in the pipe decreases until reaching the saturated vapor pressure. The fluid is completely liquid during this step.
- Step 2: A vaporization wave goes through the pipe in counter flow. The pressure decreases in the area reached by the vaporization wave and the fluid is two-phase.
- Step 3: The vaporization wave have reached the limits of the pipeline, the fluid is two-phase in the whole pipeline. The pressure in the pipe decreases until reaching the atmospheric pressure.

THE "EVANUM" MODULE: POOL SPREAD AND VAPORIZATION FOR LNG SPILL

Description of functions and theory

The EVANUM module has two main functions: to calculate the pool extension and to evaluate the vaporization rate. EVANUM can model a spread on land or water, in free field or inside a bund. A database based on experimental measures gives information on soils (minimal thickness of liquid, thermal conductivity,…) which are necessary for the calculations (Figure 4).

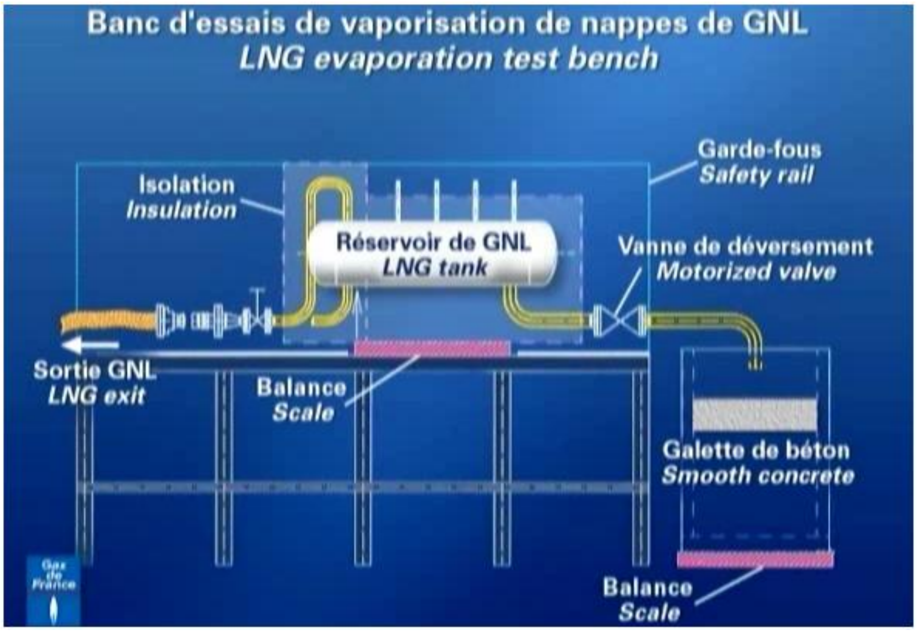

Figure 4: Principle scheme of the LNG vapor test bench build by GDF SUEZ to calculate the soil characteristics

The EVANUM module is particularly accurate to model a pool spread inside bunds. It takes into account the spread on the soil, the increase of the height of liquid, the overflowing of the bund and the extension in other bunds. This function enables to solve real situations around tanks in some LNG terminals or liquefaction plants.

EVANUM is an integral code using some semi-empirical formulas and different assumptions to simplify and adjust the calculations. For example, the pool depth is considered homogeneous and the pool vaporization is only caused by the thermal exchange between LNG, the soil and the bund walls (convective exchange with air and sun radiation are considered negligible).

Validation of the model

The accuracy and validity of the EVANUM module essentially depends on the soil parameters: minimal pool thickness and thermal exchange coefficient. Numerous medium and large scale LNG spill have been realized on several types of concrete, sand and others porous soils. Thanks the experimental results, EVANUM is strongly validated for the different situations encountered on LNG terminals and liquefaction plants.

The comparison between EVANUM results and experiments shows the good accuracy of the model to predict the pool dimensions (Figure 5). The deviation with the experiments is generally below more or less 30%. In some cases, the pool radius is overestimated above 30% but it is more rarely underestimated below -30%.

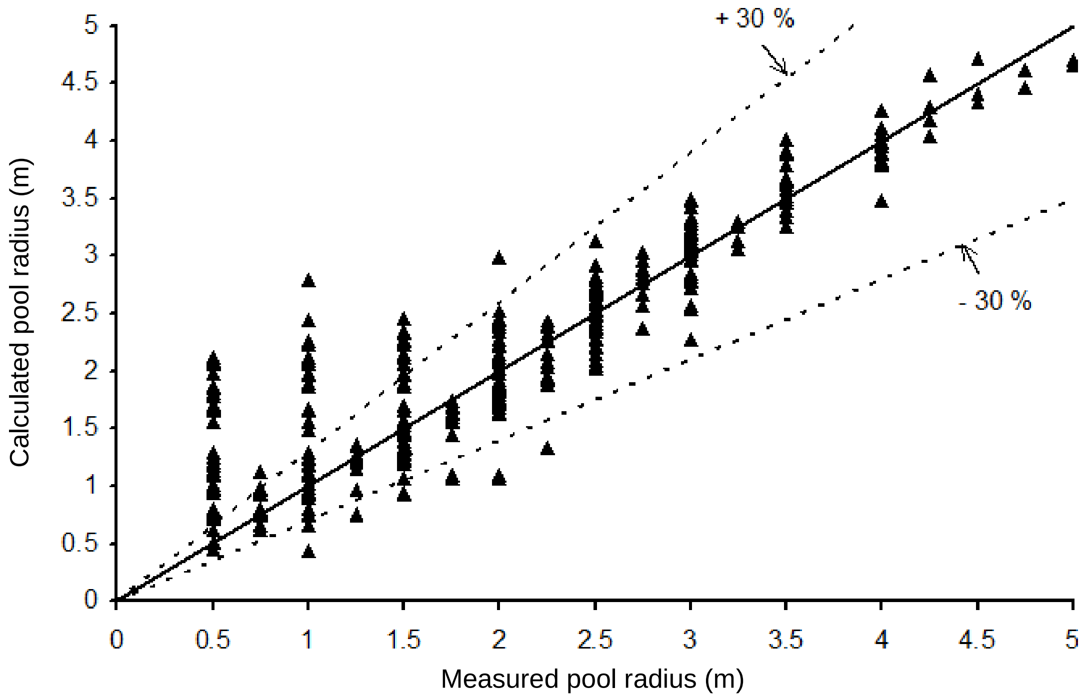

Figure 5: Comparison between measures of pool radius and calculations

To conclude, the EVANUM module is rather conservative in the calculation of the pool spread and vaporization.

THE “EOLE” MODULE: DISPERSION OF LNG VAPOUR CLOUD AND PRESSURIZED JET

Description of functions and theory

The EOLE module is able to model the gas dispersion and to determine the distance to the Lower Flammability Limit of LNG vapor (heavy vapors) for different scenarios:

- a puff release (instantaneous release),
- a vaporization of a pool in taking into account the variation of pool size and vaporization rate
- a pressurized release (flashing liquid jet).

A LNG vapor cloud from a pool (Figure 6) is different from a pressurized jet (Figure 7), since it has neither initial velocity nor liquid droplets. EOLE distinguishes the four following steps for a pressurized jet and only the last two are applicable for LNG vapor from pool:

- Jet dispersion with droplets (two phase),
- Jet dispersion after droplets vaporization,
- Gravity based dispersion,
- Passive dispersion.

Figure 6: LNG vapor cloud from a pool – the vapor cloud is first very closed from the ground due to its density and then rise due to buoyancy and passive dispersion

Figure 7: LNG pressurized jet – the jet is first horizontal above ground due its initial velocity, then fall to the ground due to gravity and finally rise due to buoyancy and passive dispersion

The dispersion models take into account the meteorological conditions defined by the wind speed and atmospheric stability (Pasquill stability classes).

Validation of the model

The validation of the EOLE module is based on several test campaigns generally performed with LNG, but also with other heavy gas (ammonia, propane, freon-azote mixture). Different types of dispersion were tested : continuous releases on water, instantaneous releases on land, high-pressure jets. Among the validation data, the campaign of Maplin Sands, Thorney Islands and Burro are the most famous.

The comparison between EOLE results and experiments shows the good accuracy of the model to predict the distance to the Lower Flammability Limit (Figure 8).

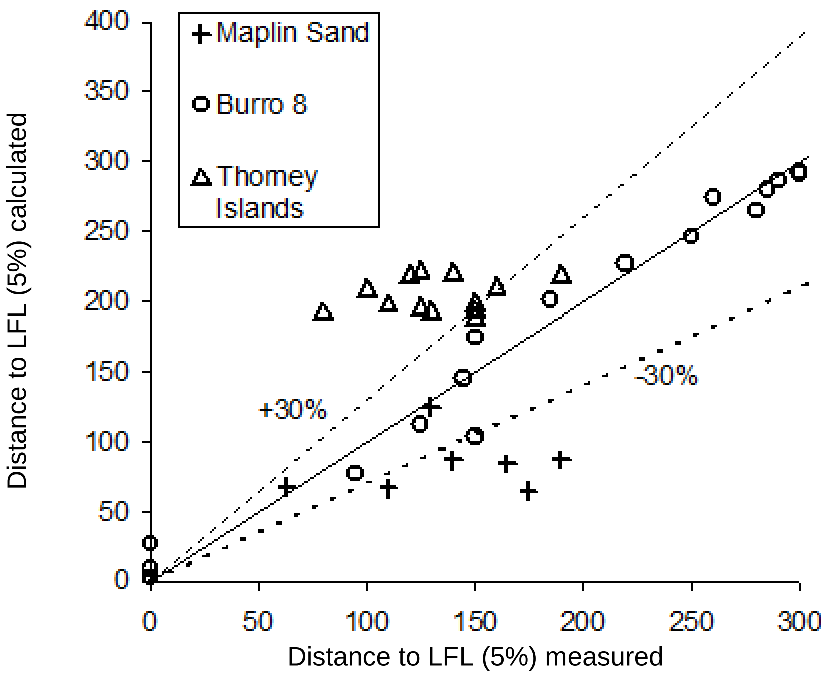

Figure 8: Comparison of EOLE results with experimental data (distance to LFL)

For continuous releases at steady flow rate (Maplin Sands and Burro), EOLE predicts the distance to LFL with a good accuracy for low wind speed (between 1.5 and 5 m/s), but tends to underestimate the distance for high wind speed (> 5 m/s). However, these conclusions might be qualified due to the quality and quantity of experimental results from the Maplin Sands campaign.

For instantaneous releases (Thorney Islands), EOLE is reasonably conservative to estimate distance to LFL. In this case, the data are more reliable.

For pressurized jets (Figure 9), EOLE gives accurate and conservative results. For 108 measures of concentration during the test, 50% are overestimated (very few above 30%) and, among the other 50%, 93% are hardly underestimated (deviation below -30%).

The validation of EOLE is reinforced by comparisons with CFD code (Mercure) and by a sensitivity analysis to determine the influence of each parameter.

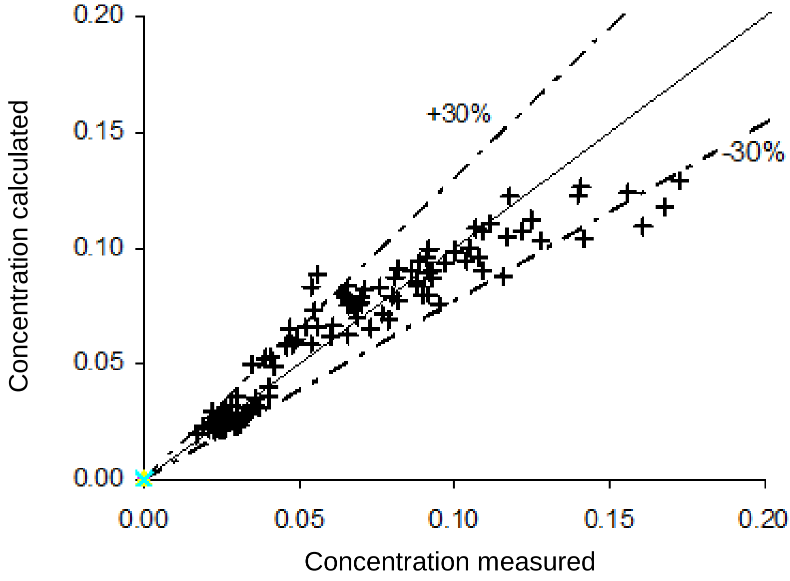

Figure 9: Comparison of EOLE results with experimental data (concentration)

To conclude, the EOLE module is rather conservative in the calculation of LNG vapor dispersion and flashing liquid jet.

THE "CORE" MODULE: LNG POOL FIRE WITH OR WITHOUT EXTINCTION SYSTEM

Description of functions and theory

The CORE module calculate the dimensions of LNG pool fires and the heat radiation emitted by the flame. The pool fire can be modeled in free field or inside circular or rectangular bunds. Thanks to numerous experiments with foam addition, CORE can calculate a scenario in taking into account the efficiency of the foam to extinguish the fire (Figure 10).

Figure 10 : These two pictures illustrate the efficiency of foam addition on flame size.

The CORE model is based on semi-empirical relations to determine the flame characteristics (height, angle, emissivity) and uses a solid flame model to calculate the heat radiation. The solid flame is either an angled cylinder (Figure 11) or an angled pallelepiped depending on the shape of the bund.

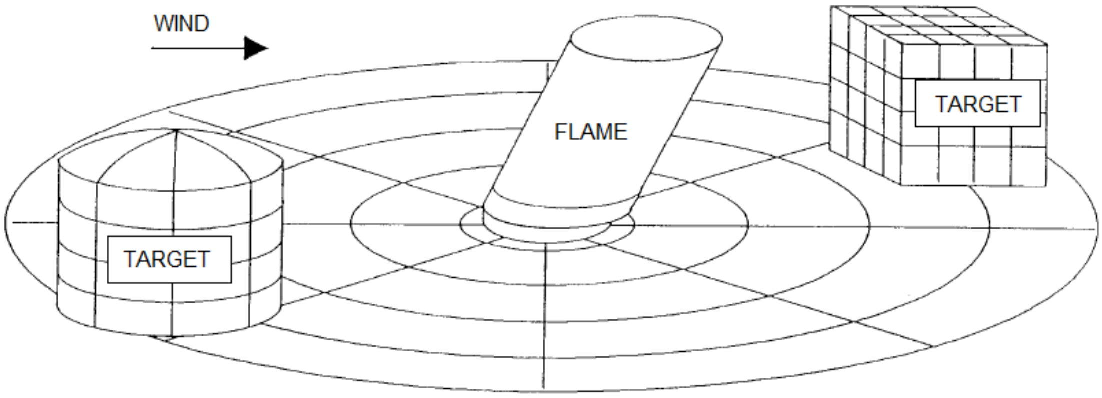

Figure 11: CORE uses a solid flame model to calculate the heat radiation received by different targets (building, tank, …)

The models take into account the meteorological conditions defined by the wind speed and the humidity in air to calculate the flame angle and the absorption of radiation in the air.

Validation of the model

The CORE module is validated on numerous experimental fires performed by GDF SUEZ during the past decades, in its own test facilities. Among these experiments, the tests of Montoir-de-Bretagne (Figure 12) are still the largest LNG fires on land, with a pool diameter of 35 m (pool surface = 1000 m²).

Figure 12: The experiments of Montoir highlight the influence of soot formation for large pool fire.

The comparison of heat radiation measures and the results of CORE (Figure 13) demonstrates the good accuracy of the model. Most of the values are slightly overestimated by the model and deviation below -30% are very rare.

To conclude, the CORE module is rather conservative in the calculation of the LNG pool fire and is very useful to take into account the performance of foam addition.

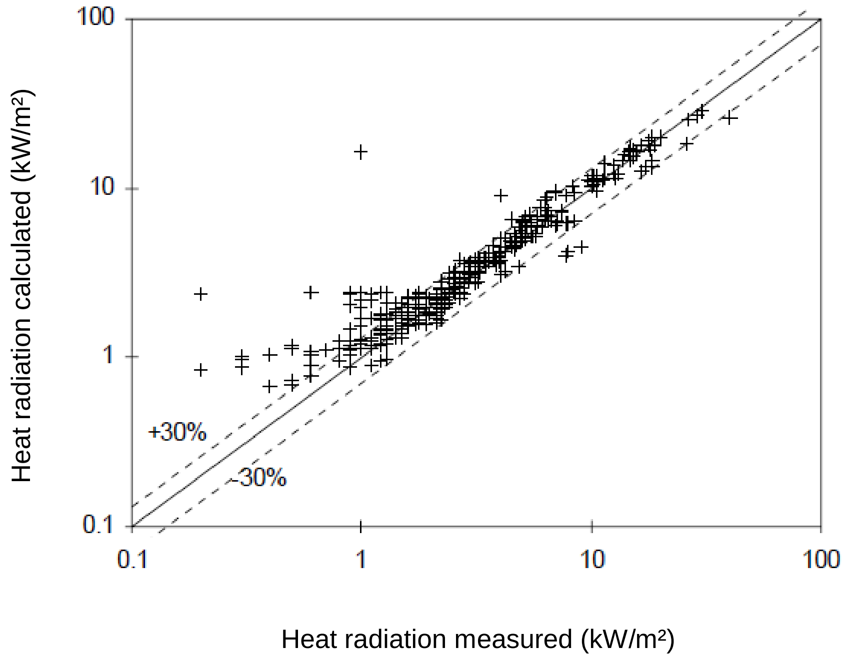

Figure 13: Comparison of experimental measures of heat radiation with results from the CORE module

CONCLUSION

The EVOLCODE package is an easy-to-use and fully validated tool to evaluate the consequences of LNG loss of containment in an open area.

It relies on a solid experience feedback. Some modules are directly based on the fluid mechanics and combustion and others are based on semi-empirical formulations. Moreover, each module has been largely validated on large-scale experimental.

EVOLCODE is constantly improved so far, by adding new models assessing the effects of other physical phenomena. For instance, some actual developments concern the overheating of cryogenic pipe or equipment due to heat radiation, the use of thermal dose to estimate the consequences on human beings.

Development of off-shore LNG facilities is also a driving force behind the enhancement of models to evaluate the consequences of LNG releases on water or subsea. GDF SUEZ is constantly vigilant to launch or to be involved in new theoretical and experimental research on these subjects.