

A NEW CONCEPT FOR LNG IMPORT TERMINALS, IN RESPONSE TO THE NEW SECURITY AND SAFETY CHALLENGES

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1. INTRODUCTION

The design of a LNG import terminal imposes new challenges due to increased community sensitivity to, and awareness of industrial safety, especially as a consequence of September 11, 2001 terrorist attacks.

Furthermore, most LNG import terminals are located in busy harbours, close to unrelated facilities and inhabited areas, thus requiring focus on layout optimisation and hazard distances.

In the future, industry and the authorities will have, even more than in the past, to quantify and explain to the neighbouring community the effects on the inhabited areas of the worst case scenarios in plants using hazardous materials.

During the permitting process of future LNG terminals we will have, nearly always, to answer the question: "**what would happen in the case of a rupture of the concrete wall of a full containment LNG tank, whatever the cause?**" even though such an event is not considered as a possible one from an industrial point of view.

In our opinion, however, whilst an additional level in risk management, in response to the new terrorist threat, should be considered, our existing safety rationale behind the management of "**normal**" industrial risk should **not** be modified.

TotalFinaElf design principles for LNG terminals are based on the best international Codes & Standards and the following basic specifications:

- double-containment or full-containment technology for all LNG tanks,
- plant layout and internal safety distances based on "Credible Events" (i.e. likely to occur during the life of the plant) selected on probability grounds,
- fence location and outside safety areas for land planning based on "Major Events" according to the local regulation framework, and taking into account all the "normal" industrial risks, such as: geotechnical, seismic, atmospheric, vehicles impacts, small aircraft crashes, unloading arm rupture, roll-over, inner-9%-Ni-tank rupture... **But we never consider the rupture of a full-containment storage tank structure as a possible Major Event.**

Nevertheless, today it seems unavoidable that we evaluate the consequences of such a scenario resulting from a deliberate attack and put forward new solutions acceptable to the neighbouring community.

To add a third containment wall around a full containment tank is clearly an expensive and inefficient solution (the third wall could be damaged as well as the second, in case of big aircraft crash or attack with war weapons). Then, if the site conditions do not allow very large safety distances between the terminal and the sensitive population centres (inhabited areas, schools, hospitals, highways, railroads...) other solutions should be found.

2. THE NEW RUE CONCEPT

A novel solution explored here is to add a remote ultimate impoundment (in French: RUE = Rétention Ultime Eloignée) around an onshore terminal equipped with aboveground full-containment tanks. It consists in a slope or a bund of about 1.5 m high, made of earth or stone, that rises up all around the tank farm or even the whole terminal, at a distance greater than 100 m from the tanks, and has a volume higher than the capacity of the biggest tank (see diagram 1)

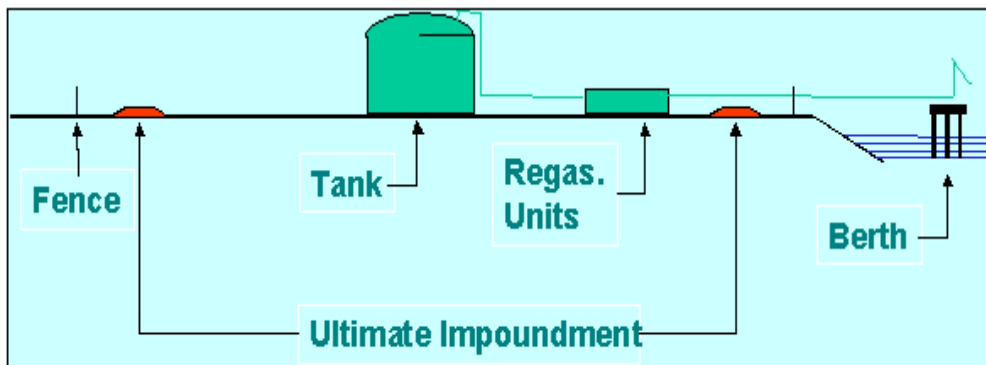


Diagram 1: RUE concept schematic

This barrier:

- is completely passive, without any maintenance requirement,
- is not destroyed because of the distance, even in the case of an aircraft crash on a tank,
- does not generate any additional risk, either during construction phase or in operation,
- has a low cost.

As it is not designed for a "Major Event" It is clearly not a conventional containment system but responds to an extremely unlikely catastrophic one.

The RUE aims at limiting the extension of the LNG pool towards the inhabited zones, but is not designed to protect the terminal facilities themselves. It can thus be placed at the boundary of the terminal and can include, if necessary, all the units and buildings.

In the case of a catastrophic release of LNG from a tank, the units and buildings located inside the RUE would be damaged or even destroyed, but the affected area outside the terminal would be significantly reduced, thus avoiding catastrophic effects on neighbouring inhabited areas.

The RUE is clearly a complementary barrier with a different aim from the usual containment systems, which remain relevant.

To validate this concept it has been necessary to run computer simulations of:

- the extent of the LNG pool in case of major release without RUE, in order to evaluate the benefits of the later,
- the extent of natural gas cloud without fire in the RUE,
- the thermal radiation distances in case of fire in the RUE,
- the motion of LNG during the spillage in order to find a design which prevents wave-effect overflow.

3. 2D STUDIES

3.1 Approach

We have decided in an initial approach, to study the effects of different LNG catastrophic spill releases, **with and without remote impoundment area**, to assess the advantage of the RUE concept.

This initial and simplified approach has been based on 2D modelling with the aim of assessing the effect of various parameters, such as the hole size in the tank, on the hazard distances.

The hazard consequences have been calculated in terms of distance of the LFL (Lower Flammable Limit) and thermal radiation in the most probable case of a LNG pool fire due to burn back from an ignition source reached by the gas cloud.

3.2 2D modelling method and tools

General hypotheses:

- total spilling of a 170 000 m³ (78 104 t) LNG tank onto the ground as a consequence of a hole in both the inner tank and the concrete external structure,
- tank diameter = 80 m, LNG level H = 34 m,
- the hole is located at a height of one metre above the ground,

Main parameters:

- diameter of the hole: 0.05, 0.10, 0.50, 1.00, 2.00, 3.00, 4.00 and 5.00 m
- absence / presence, of the RUE (11.5 ha in area),
- type of terrain: earth or sea water,
- atmospheric conditions (stability, wind speed, temperature): F2 and D5 conditions have been considered.

The source term is estimated for each scenario: LNG release rate and spreading of the liquid pool on the ground (or in the impoundment area). Evaporation of the pool and the total gas flow rate are therefore evaluated.

Then, the gas dispersion and ignition of the pool formed on the ground are modelled. The maximum distance to the LFL and the distances corresponding to different thermal radiation are estimated for each scenario (3 and 5 kW/m²: threshold values recommended by French authorities respectively for beginning of blistering and for beginning of fatalities effects (1%) after more than one minute of exposure).

The source terms and atmospheric dispersion are calculated using the PHAST software program developed by DNV Risk Management Software. The calculations obtained are used to evaluate and visualise the characteristics of the plume of gas: shape, dimensions and concentration according to the distance and time. The weather conditions, the wind speed and atmospheric stability, and the surrounding terrain – flat, agricultural, industrial or urban – are also taken into account. However, the effect of the topography and possible obstacles is not modelled.

The thermal radiation is calculated with a special PHAST module called "pool fire" which calculates, on the basis of an equivalent diameter (pool or impoundment area), the mass flow rate of combustion gases, the height and tilt of the flame, and the thermal radiation according to the wind speed and distance.

This study has been carried out by EADS-APSYS.

3.3 Results

Tables 1 and 2 below show the main results of this 2D modelling study for both cases with and without impoundment area on earth. The distances are expressed from the centre of the tank and for a maximum release time of one-hour (limit of the software modelling).

Calculation results for the case of a spill on **seawater** are not presented because they show very bigger distance to the LFL compare to a spill on earth surface. Indeed, LNG evaporation rate on seawater is much higher than on earth due to infinite thermal contribution capacity of the sea.

Thus, the design of a LNG terminal should avoid that a large LNG spill would spread towards the sea. This is the case of the RUE concept.

Breach diameter [mm]	LNG flow rate from the tank [kg/s]	Maximum distance to the LFL [m]		Distances to the thermal radiation [m]			
				5 (kW/m ²)		3 (kW/m ²)	
		F2	D5	F2	D5	F2	D5
50	3.43	99	38	18	15	21	17
100	13.73	214	65	65	57	80	68
500	343.14	844	129	509	436	637	531
1,000	1,372.56	1,438	192	964	842	1,198	1,033
2,000	5,490.22	2,859	292	1,559	1,654	1,931	2,004
3,000	12,353.01	4,210	431	2,183	2,103	2,674	2,557
4,000	21,960.9	4,253	443	2,918	2,841	3,562	3,420
5,000	34,313.91	4,722	468	3,146	3,073	3,840	3,701

Table 1 – LNG release from tank on earth without impoundment area

Breach diameter [mm]	LNG flow rate from the tank [kg/s]	Maximum distance to the LFL [m]		Distances to the thermal radiation [m]			
				5 (kW/m ²)		3 (kW/m ²)	
		F2	D5	F2	D5	F2	D5
50	3,43	96	38	18	15	21	17
100	13,73	214	65	65	57	80	68
500	343,14	844	129	509	436	637	531
1,000	1,372.56	1,438	192	964	843	1,198	1,033
2,000	5,490.22	2,811	241	1,072	1,076	1,332	1,313
3,000	12,353.01	3,445	415	1,072	1,076	1,332	1,313
4,000	21,960.9	1,221	216	1,072	1,076	1,332	1,313
5,000	34,313.91	720	207	1,072	1,076	1,332	1,313

Table 2 – LNG release from tank on earth with a circular impoundment area (radius: 190 m)

These results show that the maximum LFL distances are reached for the hole diameter of 3 m and not for 5 m as shown on Table 2. The explanation is that for this impoundment surface, the LNG pool spreading corresponds to a maximum evaporation rate.

3.4 2D studies conclusions

The 2D modelling study has demonstrated the advantage of using the RUE concept.

Actually, without the RUE the hazard distances increase continuously with the size of the hole, and can reach several kilometres. The remote impoundment system clearly helps to prevent the LNG pool from spreading, and therefore limits the maximum hazard distances in the case of a catastrophic release (hole diameter > 1 m). This confirms that the RUE is a relevant concept for worst case scenarios related to deliberate attacks. On the other hand it does not cope with the "Major Events" usually taken into account, for which the classical containment systems remain relevant.

For the impoundment surface considered (11.5 ha), the evaporation rate is at its maximum for a hole diameter of 3 m corresponding to a balance between LNG release rate and LNG evaporation rate according to thermal conductive exchange with the soil.

The potential effects (distance to the LFL) of atmospheric dispersion shows **inconsistencies** between F2 and D5 atmospheric conditions (LFL distances ratio 1 to 10).

These results have led us to pursue the studies and to use more precise 3D modelling tools to assess the hazard distances to such a catastrophic scenario by taking into account all the parameters like topography, obstacles, shape of the impoundment surface, actual wind speed vertical distribution, etc.

Moreover, the previous results have shown that the guarantee to contain the LNG spill in the RUE is a key point to minimise the hazard distances. So, for a hole diameter of 3 m the wave effect should be modelled to adapt the impoundment geometry, using 3D fluid dynamic software.

4. 3D STUDIES

On the above basis, the scenario we have selected is a hole diameter of 3 m occurring on a 170,000 m³ LNG tank. We have considered the actual layout of a TotalFinaElf LNG receiving terminal project. The initial design of the remote impoundment has been made taking into account the actual topography and obstacles existing on the site (see diagram 2-1)

A first impoundment surface of 42,000 m² is delimited all around the tank by a slope of 1,5 m with the aim of limiting the risk of overflow by a reduction of the wave speed. A second impoundment surface of 135,000 m², delimited by a bund of 1 meter high is located at a rather longer distance. They form together a volume higher than the capacity of the tank in order to allow all the LNG tank capacity to be contained.

The purpose of this containment system is to limit the extension of the LNG pool towards the inhabited zones, but not to protect the terminal facilities themselves. Thus, the second bund is located in periphery of the terminal and includes all the units.

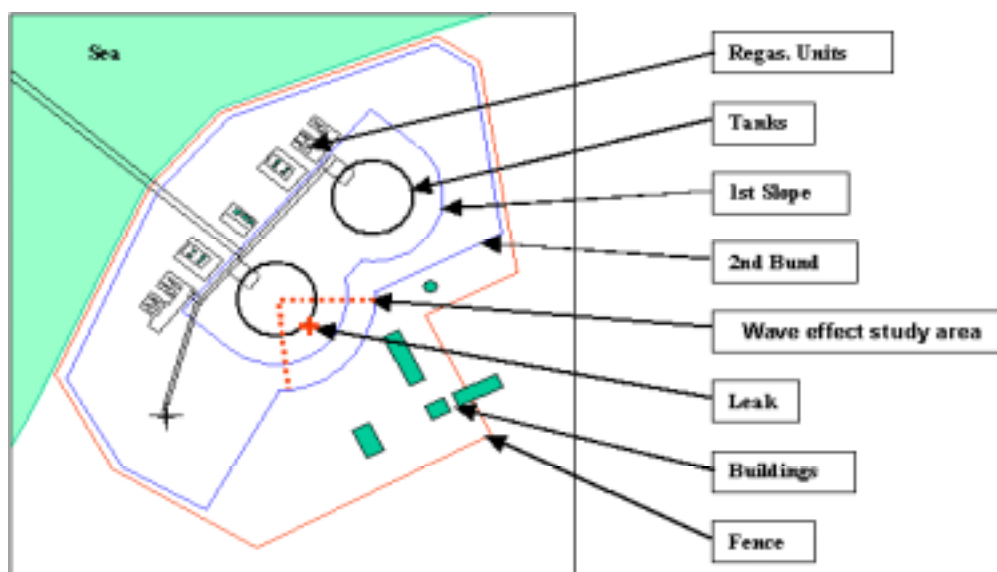


Diagram 2-1 - General lay-out for 3D studies

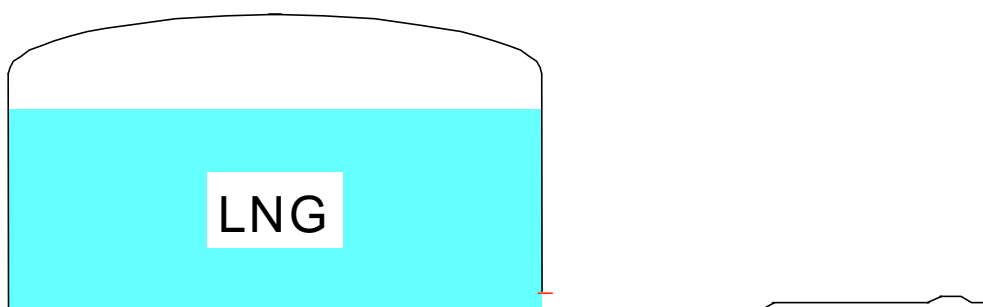


Diagram 2-2 - Side view of LNG tank and RUE in the direction of the jet

Three phenomena have been modelled:

- Wave effect and LNG spreading during the filling of the retention.
- Dispersion of the natural gas cloud formed during evaporation of the pool. Three atmospheric conditions for dispersion have been considered: F2, B2 and D7 according to Pasquill classification.

- Pool fire and thermal radiation associated for two atmospheric conditions (weak and average wind).

For the study of these phenomena, TRANSOFT relied on its range of software of fluid mechanics. The work carried out can be broken down into four stations:

- Set up of three different numerical models and 3D grids: the first one including the tank and the jet area, the second one including the full retention system and the last including the surroundings of the terminal up to 4 km downwind.
- Modelling of the wave effect and spreading in the retention. The software used for this part of the study is the fluid dynamics software **fluidyn – NS** (VOF method).
- Modelling of atmospheric dispersion. The software used, **fluidyn - PANACHE** simulates the dispersion of the pollutants using the 3D resolution of fluid dynamics. The phenomena affecting dispersion are the ground roughness, the vertical thermal stratification, the turbulent diffusion, etc.
- Modelling of the LNG poolfire of GNL with the software **fluidyn – PANFIRE** based on the TNO methodology for pool fires.

4.1 3D atmospheric dispersion

Simulation assumptions

The model includes the ground model (topography, obstacles, ground occupation), the weather conditions and the emission sources.

The chosen weather conditions are applied to the limits of the simulation field and the software defines the wind and turbulence fields. The simulation being 3D, the weather conditions change with altitude. The atmospheric conditions (Pasquill classes and variation in temperature) as well as the mixing height are selected to be the most penalising.

For the emission evaporation flow rate assessment, a certain number of assumptions and simplification are taken into account:

- The emission mass flow rate strongly depends on the thermal exchange between LNG and air and between LNG and soil. An analysis of the different thermal convective exchanges between LNG pool, soil and air demonstrates that the **thermal air contribution can be considered as negligible in the evaporation rate calculation due to the atmospheric stratification over the pool.**
- The initial conditions taken into account for dispersion modelling study correspond to a stabilised situation with the impoundment surface considered totally filled and full of GNL. **Thus, the spill phase is not considered.**
- To calculate the convective heating between ground and LGN a **50 cm height turbulent boundary layer** is considered inside the fluid. A specific simulation has been made on the sensibility of this parameter, which is lower during the spreading phase. Given the size of the hole in the tank and the wave effect study previously carried out (Cf. Part 4.4), the LNG pool fills up very quickly the impoundment area around the tank. Results of the simulation demonstrated that for different heights of turbulent boundary layer, the gas evaporation flux was not underestimated in keeping with the previous assumptions.
- A simplifying assumption had to be made due to the complexity of the ground features under the pool. Instead of a 3D model, a simplified 1D model of heat propagation in the ground shows that the value of -70°C should be a minimum for ground surface temperature. On the other hand, keeping the initial soil temperature at its initial value of $+10^{\circ}\text{C}$ give the upper bound for the estimate of the evaporation rate. The actual soil temperature should be between these two extreme values
- considering the value of -70°C the evaporation flowrate is 930,8 kg/s, and the emission lasts 21 hours.
- considering $+10^{\circ}\text{C}$. the evaporation flowrate reaches 1,758 kg/s and the duration of the emission is reduced to 11 hours.

Results

The Table 3 below shows that for weak wind velocities, stable atmosphere and maximum emission (F2; soil at +10°C), the gas cloud does not disperse very much, **320 m for the LFL**. Furthermore the results have shown a weak vertical propagation and a weak side transport.

For other wind and emission conditions the conclusions are as follows:

- For F2 conditions and with a reduced emission (soil at -70°C), the cloud directly above the pool will not stay homogeneous.
- For an average wind condition and a neutral class of stability (D7; soil at +10°C) the diffusion by thermal turbulence is reduced, on the other hand dispersion by the moderate wind is more significant. Thus the cloud stays in the vicinity of the pool.
- For a condition of reduced emission (D7; soil at -70°C) the cloud geometry is almost identical. In fact, the vertical penetration of the cloud is weak and erosion of the vapour cloud occurs above the pool.
- For a condition of weak but very unstable wind (B2), turbulence strongly develops and induced dispersion is very intense.

For all these cases, the results analysed in terms of iso-surfaces and concentrations at ground level show that clouds with concentrations higher than the lower flammability limit (LFL) of 36 g/m³ and half the LFL (18 g/m³) remain **confined to the impoundment area or in its immediate vicinity**.

Hole diameter: 3 m				
Ground temperature	Evaporation flow rate [kg/s]	Maximum distance to the LFL / 50 % LFL [m]		
		F2	B2	D7
+ 10 °C	1,758	320 / 480	93 / 242	307 / 498
- 70 °C	931	257 / 330	88 / 93	262 / 360

Table 3 – 3D atmospheric dispersion modelling with RUE

4.2 Simulation of thermal radiation related to the LNG pool fire

To make a hole of 3 m in the concrete structure of a full containment tank requires a considerable amount of energy. Following such an event, multiple ignition sources may be found all around the damaged tank. So it is expected that the ignition will burn back to the source, causing a pool fire to develop. Thus, **the pool fire scenario is much more probable than the gas dispersion one**.

Simulation assumptions

For this simulation, the RUE retention is supposed to be full of LNG. **The exact geometry of the bund is taken into account**. Two wind speeds (average: 7 m/s and weak: 2 m/s) are selected. This study presents the results of the hazard distances corresponding to the 5 and 3 kW/m² thermal radiation thresholds (threshold values recommended by French authorities respectively for beginning of blistering and for beginning of fatalities effects (1%) after more than one minute of exposure)

A reference value from the SFPE Handbook for LNG combustion rate is used for flame height calculation and estimate of fire duration.

Results

The duration of the fire is estimated to approximately 6,640 s and height of flames are about 300 m. Thermal radiation results are shown in the Table 4.

Hole diameter: 3 m			
Distances to the thermal radiation [m]			
5 (kW/m ²)		3 (kW/m ²)	
F2	D7	F2	D7
542	547	721	697

Table 4 – 3D poolfire thermal radiation modelling with RUE

4.3 Comparison and analysis of 2D and 3D modelling results

To have a better comparison between 2D and 3D modelling tools, a complementary 2D modelling study has been made with a circular (207 m radius) impoundment surface of 135,000 m² as the same in 3D studies.

Table 5 below shows the results of LFL dispersion and thermal radiation between 2D and 3D studies.

Hole diameter: 3 m									
Modelling study	Distances of gas dispersion					Distances to the thermal radiation for pool fire [m]			
	Evaporation flow rate [kg/s]	Maximum distance to the LFL [m]				5 (kW/m ²)		3 (kW/m ²)	
		F2	B2	D5	D7	F2	D7	F2	D7
3D modelling study with high ground temperature	1,758	320	93		307	542	547	721	697
3D modelling study with low ground temperature	931	257	88		262				
2D modelling study	3,474	3,302		421		1,144	1,147	1,416	1,396

Table 5: Results comparison between 2D and 3D studies for dispersion and pool fire

Comments about dispersion modelling

2D studies **give inconsistent results between F2 and D5** atmospheric conditions for maximum distances of LFL.

Thus for F2, maximum distance to the LFL is about 3,300 m against 421 m for D5. Results obtained with 3D studies are in the range of 2D results for D Pasquill class.

The high level of difference between F2 (2D study) results and other results (2D or 3D) could invalidate the F2 condition in PHAST model for the study of LNG pool evaporation and natural gas dispersion. Indeed, in PHAST software, F2 atmospheric condition corresponds to a wind speed of 2 m/s considered at **10 m height from the ground and at a nearly null wind speed at the ground**. So in fact, air turbulence driven gas movement (proportional to the wind speed) and induced dilution are

nearly absent. Only atmospheric turbulence and a passive diffusion in air therefore generates some dispersion. This explains the 3 km distance to the LFL.

In 3D modelling, fluid mechanical equations of Navier-Stokes associated with appropriate turbulence closure for atmospheric turbulence are solved. The main advantage of the 3D fluid mechanics model, is precise accounting of the topography and obstacles to calculate very accurately the wind field and related turbulence in the boundary layer.

Comments about thermal radiation modelling

The approaches for thermal radiation calculations, resulting from a pool fire, are similar for 2D and 3D studies. The steps are:

- calculation of pool fire surface,
- calculation of flame height according to equivalent pool diameter (usually Thomas-Johnson correlation is used),
- calculation of thermal radiation from the flame taking into account initial flame radiation, view factors and absorption related to ambient air and humidity.

Table 5 indicates higher thermal radiation distance for 2D study compared to 3D study. An explanation could be that the "*late pool fire*" model has been used in PHAST calculations. This model corresponds to a pool fire ignition, which occurs when gas flammable plume has begun to disperse.

Another difference is that in the 3D modelling the flame geometry is described with a fine mesh to fit with the actual shape of the impoundment area while in the case of 2D study a cylindrical form is given to the flame.

4.4 Simulation of liquid spreading

The objectives being twofold, two different models have been used for (1) study the jet impact and overflow and (2) analyse the impoundment filling up.

Jet impact and overflow

The simulation of the liquid spreading requires a fine analysis of the wave effect at the opening of the hole. Considering that the risk of overflow is maximum in front of the hole, the simulation is limited to the part delimited by the red dotted lines on diagram 2.

So that the conditions of exit of the jet are transient and realistic, the interior of the tank is also modelled. The grid is structured three-dimensional and composed of hexaedric elements and is refined at the exit of the liquid jet.

The wave generated by the jet breaks above the first retention slope and overflows beyond the 2nd retention bund after 50 seconds. This overflow seems to weaken beyond 1,000 seconds and becomes very weak after 2,000 s whereas there remains still liquid in the tank. The maximum height of the flow above the bund is approximately 3 m. It is approximately 8 m above the edge of the first basin.

A zoom has been made on the first retention slope for the first seconds of the jet to understand the mechanisms of the overflow. The presence of the liquid is visible on the diagram 3 by the range of colours from dark blue (0%) to red (100% of liquid in the grid element). The force of the jet striking the slope clearly makes it take off. Indeed, most of its kinetic energy is transformed into potential energy (longitudinal speed is on average of 15 m/s). The liquid goes down again then, but it is noted that it does not have completely return on the ground when it meets the 2nd bund and, then overflows out of the RUE. It thus seems that the bund is too close to the edge of the first retention slope.

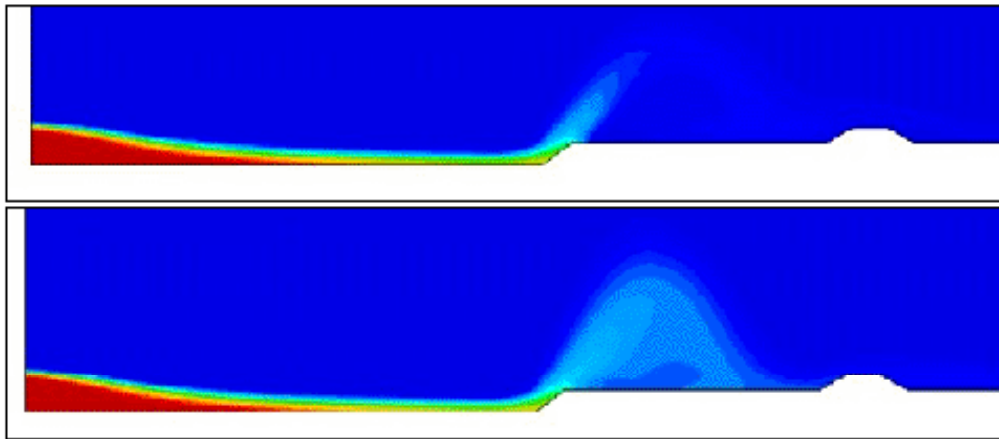


Diagram 3 - Jet impact and take off, side view in the first moments

The same first moments of the overflow can be visualised using the velocity vectors (see diagram 4) The vectors in blue indicate the air velocities, the other colours indicate the presence of LNG. In the first moments, when the basin is still completely empty, the velocity remains high (around 25 m/s) up to the edge of the 1st basin, because the fluid does not meet any obstacle. The air recirculation occurring after the edge of the basin is clearly identified.

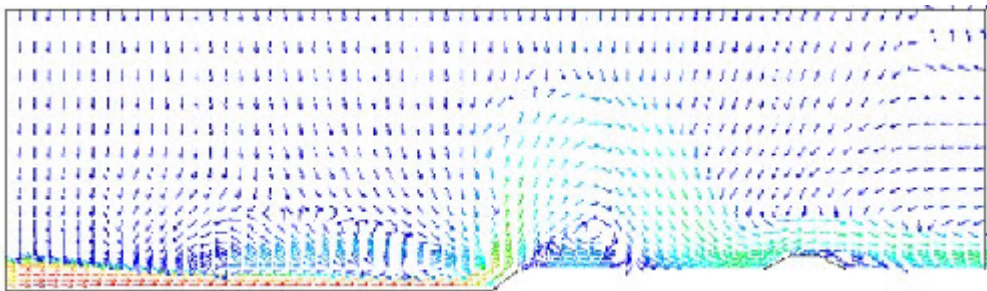


Diagram 4 - Wave effect, velocity vectors at the first moments

Although the fluid overflows almost immediately, a part of its spreading is horizontal and starts filling up the basin. It highlights the **effect of the 1st slope as wave-breaker and deflector** in keeping the wave inside the retention (see diagram 5)

Later, when the LNG fills up the first basin, the fluid already present slows the jet down and the impact speeds are lower. The maximum mass outside the 2nd bund is approximately 25 t/s, that is a total mass loss of 40,000 t.

Impoundment filling up

The full RUE is modelled including buildings, tank and regasification units. The grid is structured three-dimensional and composed of hexaedric elements. It is refined near the hole in the tank wall and in the neighbourhoods of the buildings and units.

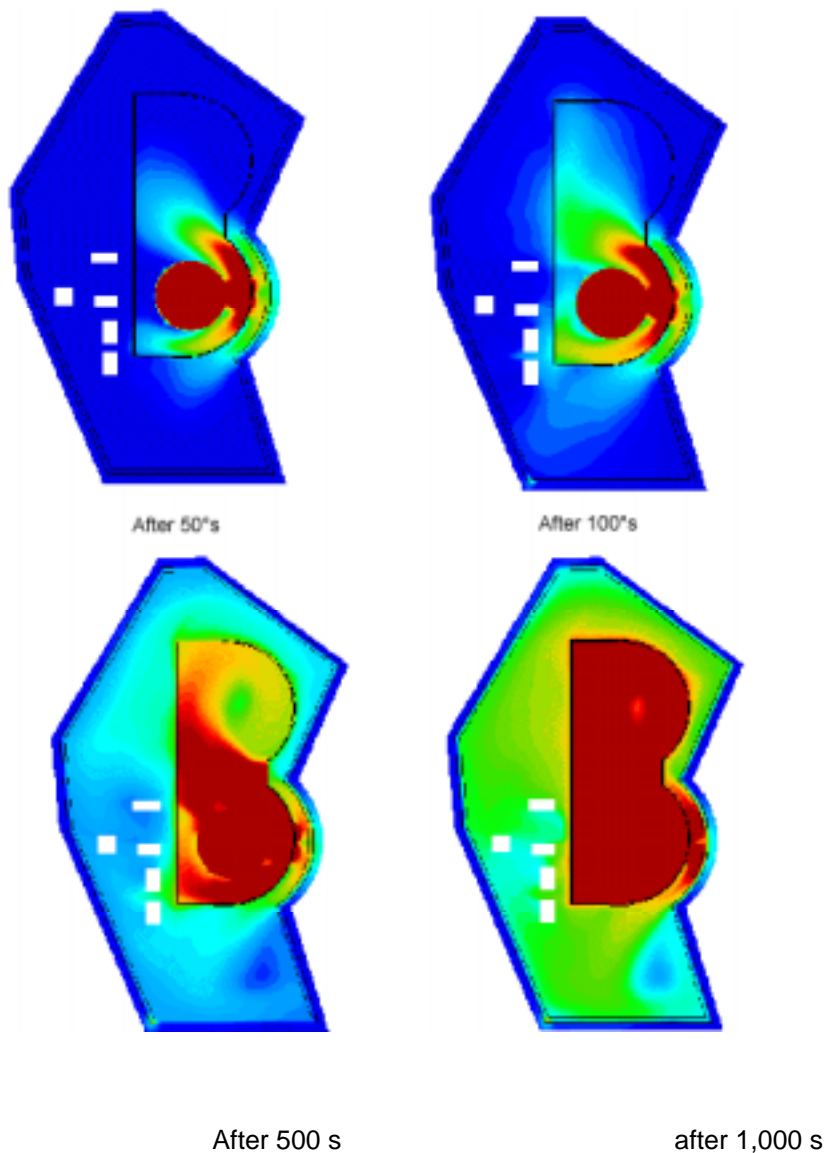


Diagram 5 - Upper view of LNG spreading

The first retention fills up entirely in approximately 1,000 s despite the fact that the jet continues beyond in the axis of the hole and above the bund. Lastly, the pool is stabilised in 4,500 s.

Provisional conclusion

In such a catastrophic scenario (3 m diameter hole!), the containment system made of a first slope ($h = 1.5$ m) and a second bund ($h = 1.0$ m) does not fill completely its role although it contains the major part of the liquid.

The first retention slope plays a major role in the side dislocation of the jet. In fact, the speed of the liquid at the passage of this slope is decreased considerably thus reducing the momentum of the jet. However, it has also for effect to help a considerable part of the liquid to take off. The bund is located then too close to the slope since the fluid does not have time to fall down on the ground before passing the last bund.

Optimisation of the design

Several modifications have been tested in order to be able to recommend a RUE geometry being both more efficient and quite easy to realise. The selected design has the following differences from the initial design (diagram 6):

- distance of the second bund increased to 100 m instead of 30 m,
- addition of two intermediate bunds 1.5 m height between the first and the last,
- slope of the 1st basin replaced by a vertical wall,
- and depth of the 1st impoundment slightly increased (2.0 m instead of 1.5 m)

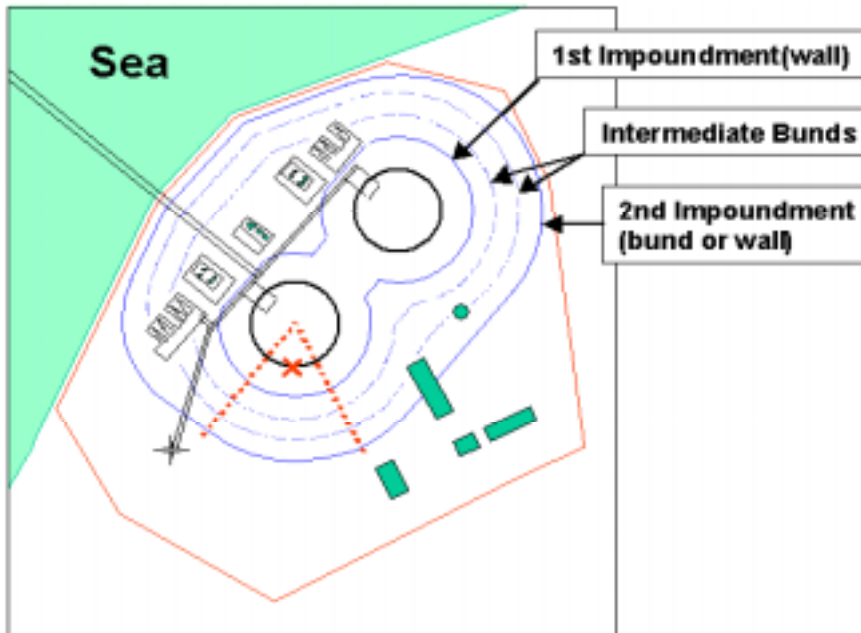


Diagram 6-1 - General layout with new design of RUE

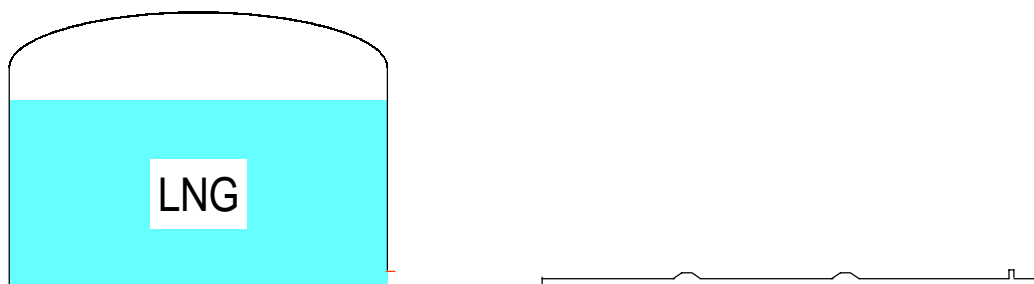


Diagram 6-2 - Side view of LNG tank and RUE (new design) in the direction of the jet

It should be underlined that the intermediate bunds, in contrast to the external one, must not be continuous, since they work only as wave breakers. So they can be interrupted when they meet a “natural” wave breaker like a building or a process unit.

Refined modelling

From the analysis of the previous simulation it appears that the VOF method (“Volume Of Fluid” method) is not able to describe properly the fluid motion after the take off. Therefore it is coupled with a ballistic sub-model. The full area is split in VOF sectors and ballistic sectors. The conservation of mass and momentum in the ballistic sectors determine the height and speed of the layer of liquid entering VOF sectors. In the azimuthal direction, the liquid is supposed to run out radially.

The results (examples are included in the diagram 7) show that almost the entirety of the spilled liquid is contained inside the fixed limits. Actually, only the very first wave manages to pass the last bund and only 60 tons of liquid (instead of the 40 000 with the initial design) are lost outside. Overpressure on the last bund is 9 mbar, which is reasonable in terms of construction.

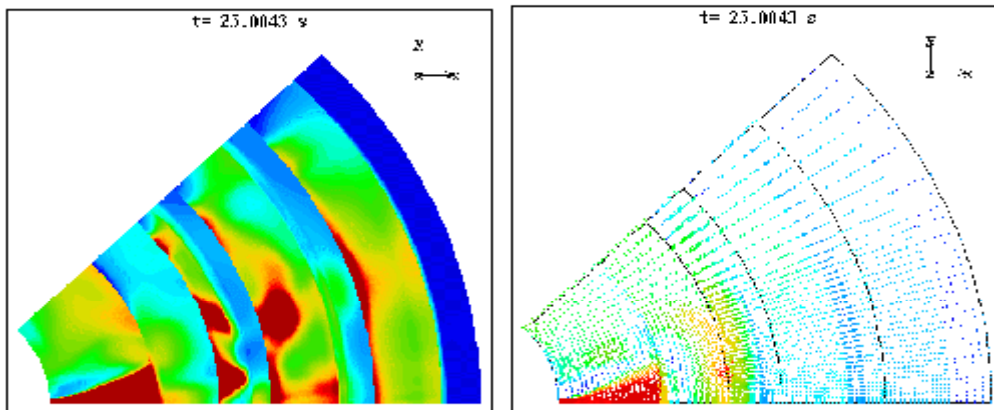


Diagram 7 - VOF method coupled with ballistic method – Upper view



Diagram 8 - Jet impact – Side view in the first moments

4.5 Conclusions of 3D simulations

Atmospheric dispersion:

For the different emission and atmospheric conditions modelled, the results analysed in terms of gas concentration show that the lower flammability limit (LFL) of 36 g/m³ and half the LFL (18 g/m³) iso-surfaces remain confined to the RUE or in its immediate vicinity.

Thermal radiation of LNG pool fire:

The results obtained show that the weather conditions have little influence on the thermal radiation – about 550 m from the centre of the tank for a threshold of 5 kW/m² and 720 m for a threshold of 3 kW/m². It should be highlighted that for the catastrophic event considered the pool fire is the most probable scenario and leads to larger hazard distances than atmospheric dispersion.

Wave effect and spreading:

From several simulations for various concepts a final RUE design has been found that avoid any overflow. Its geometry remains compatible with the layout and construction constraints of a LNG terminal.

5. GENERAL CONCLUSION

The classical simulation tools based mostly on empirical formulations do not give an accurate description of the physical phenomena in a case as catastrophic as the full release of a LNG tank content. They give for instance conservative radii of LFL. Therefore, the most precise 3D CFD simulation tools should be used in such a case, despite their higher cost.

In the case of a catastrophic release of LNG the RUE concept should allow a strong reduction of the hazard distances (a few hundred meters instead of a few kilometres). So, it could be an alternative solution to inground tanks especially in the case of proximity of inhabited areas.

This impoundment system is a complementary measure. It aims at addressing new security issues, and does not replace classical containment systems, which remain relevant.

Finally, we would like to insist on the fact that **this paper does not claim to put forward a completely proven and universal solution** for the following reasons:

- both relevance and feasibility of a RUE depends strongly on the site conditions,
- and it is impossible to predict the actual consequences of a deliberate attack against a LNG tank.

It should not be forgotten that adherence to proven Codes and Standards have led to the LNG industry having excellent safety records. The likelihood of deliberate attacks against LNG facilities is low and should be reduced further by preventive measures. Taking into account such an event, we go beyond formal requirements.

So, giving this paper, for discussion purpose only, our ambition is to contribute to the LNG industry effort in order to maintain the LNG facilities as safe and secure as reasonably practicable.