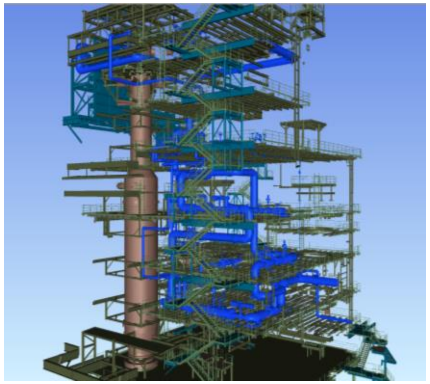
Innovative engineering to meet the needs of the energy sector

PRINCIPIA

Oil & Gas, Renewables, Naval, Nuclear



Experimental qualification of a CFD model for simulation of LNG spillage on solid structures

B. Yerly, R. Marcer, C. Audiffren

PRINCIPIA

M. Rivot, B. Lequime

Technip

R. Legent

cybernetix
A TechnipFMC Company

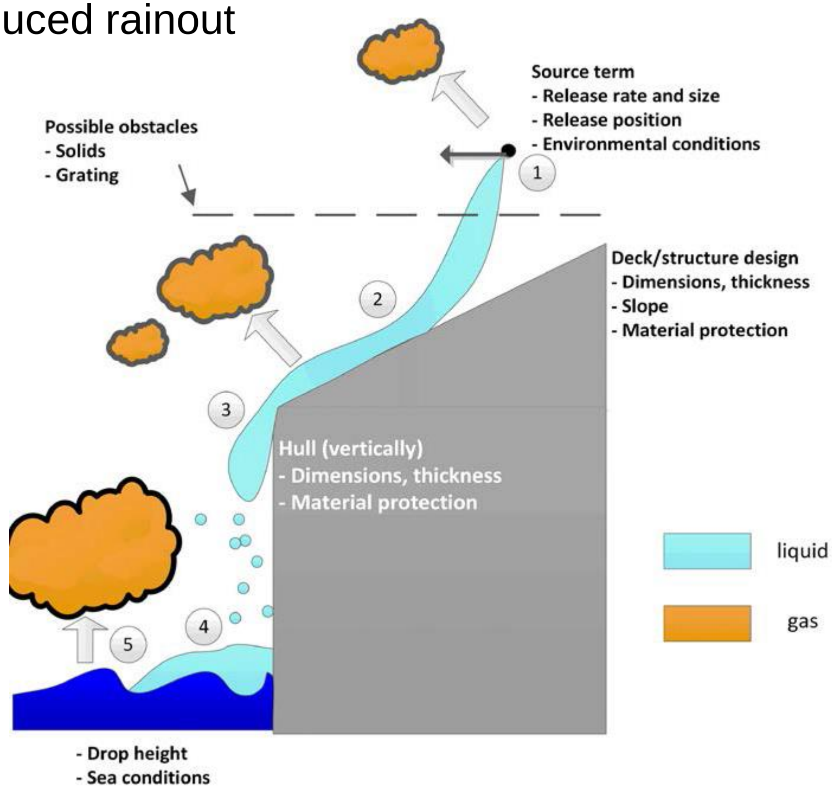
Cryogenic spill protection improvement

JIP – WP3 (2013 – 2016)

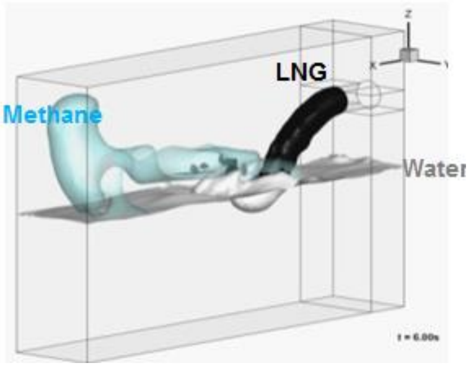
- **Led** by TECHNIP / PRINCIPIA
- **Objectives**
  - To better understand and simulate physics of cryogenic leaks in FLNG topsides (experiments)
  - To develop and qualify a CFD software for LNG spillage simulation (EOLE software from Principia)
- **Expectation** : to improve protection requirement assessment
- **Sponsors** BG GROUP, Statoil, EDF, Lloyd's Register

EOLE CFD model for LNG spillage simulation

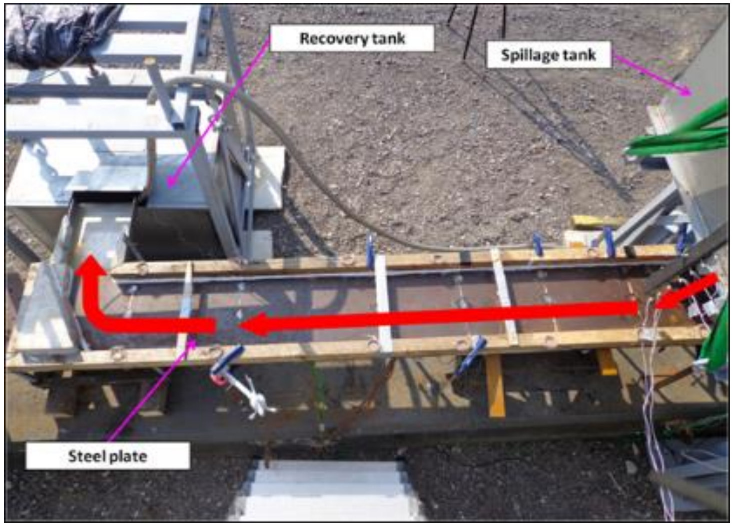
1. **LNG jet at the leak**
   - Atomization, two-phase jet (flashing) and induced rainout
2. **LNG pool**
   - Pool dynamic
   - Thermal transfer and vaporization on solid substrate
3. **LNG overtopping**
   - Volume of overflowing, liquid falling along the hull
4. **LNG pool on seawater**
   - Pool dynamic and vaporization on the sea
5. **Gas dispersion (not addressed in this study)**
   - Depending on pool vaporization and environmental conditions



A step-by-step approach for validation

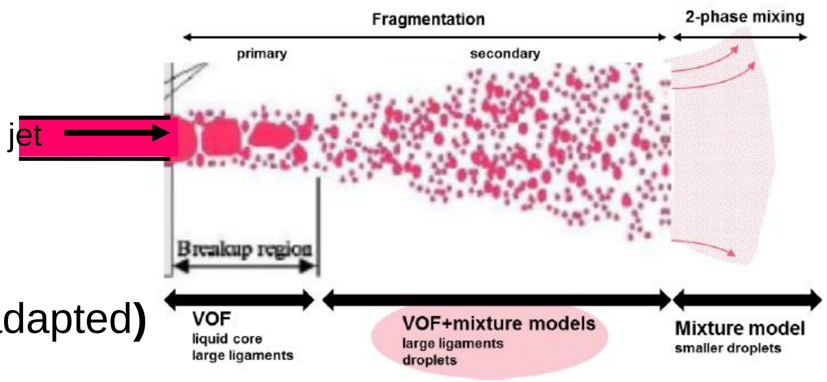


- Academic validations
- Validation from data of literature
- Quantitative validations versus intermediate scale experiments under cryogenic conditions (LN2)
  - > 120 tests in TECHNIP testing facility
  - > 150 T LN2



Main characteristics of the CFD code

- **Multiphase Navier-Stokes + turbulence**
  - LNG, vapor, water, air
- **Multi-interfaces VOF model**
  - LNG/air, LNG/water, air/water
- **Mixture model**
  - for smaller droplets (for which VOF is not adapted)



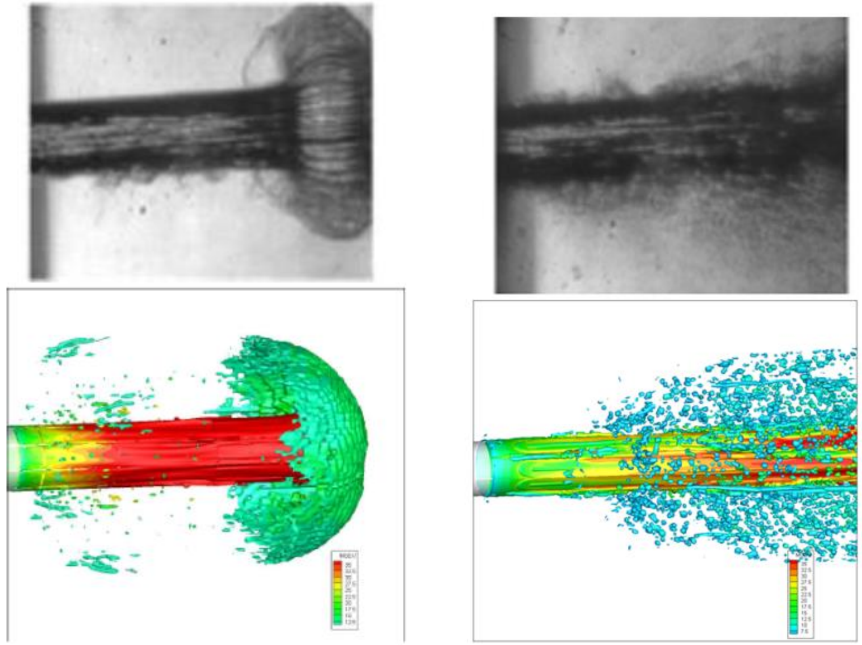
- **Vaporization model**
  - Source term in VOF and mixture models
- **Scalar transport equation for LNG vapour**
  - Depending on pool vaporization and environmental conditions
- **Thermal fluid / solid coupling**

CFD model

- **VOF equation + vaporization source term**
  - $\frac{\partial F}{\partial t} + \vec{V}.div(F) = \frac{\dot{q}}{\rho}$
  - **with** $\dot{q} = r_l F \rho_l \left(\frac{T_c - T_{sat}}{T_{sat}}\right)$
- **Mixture model (small droplets)**
  - $\frac{\partial(\rho S)}{\partial t} + \nabla\left(\vec{V}S\right) = T + \dot{q}$
  - With T=slip velocity between droplets and primary phase (air)
  - Droplets under “cell size”
- **Energy equation**
  - $\frac{\partial(\rho E)}{\partial t} + \nabla.\left(\vec{V}(\rho E + p)\right) = \nabla[(K + K_t)\nabla T] + L \times \dot{q}$
  - With *L*=latent heat
- **Transport equation for vaporized LNG**
  - $\frac{\partial(\rho C)}{\partial t} + \nabla\left(\vec{V}C\right) = \nabla[\rho(D_c + D_t)\nabla \mathrm{C}] + \dot{q}$

EOLE validation - jet

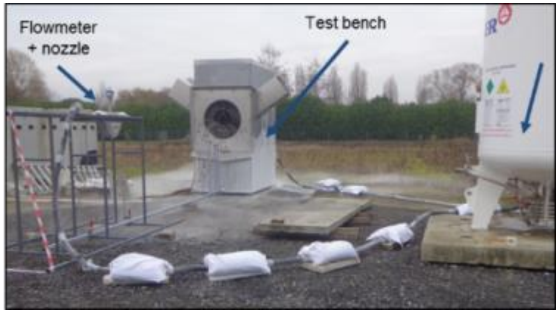
- Jet atomization

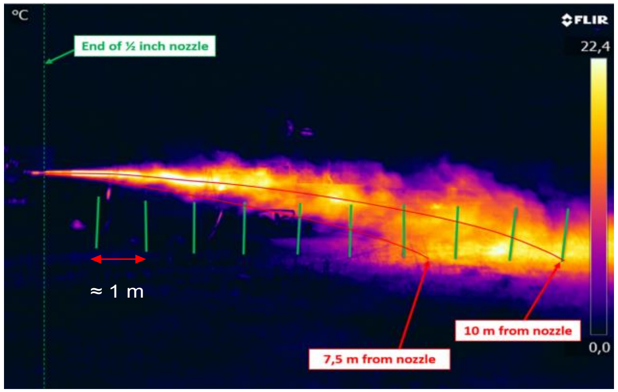


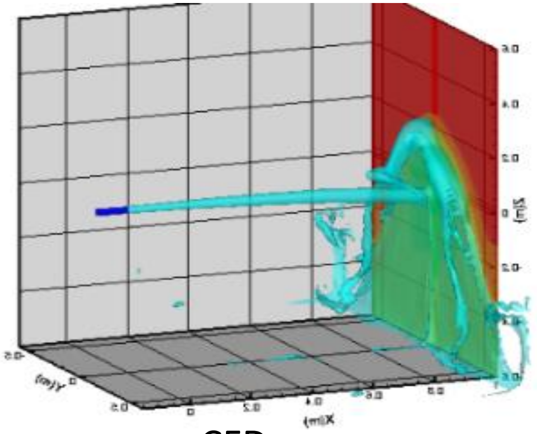
Exp. (literature)

CFD

- High pressure flashing jet





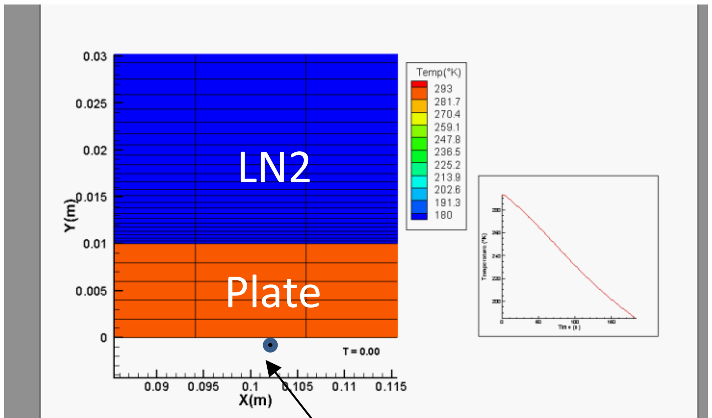


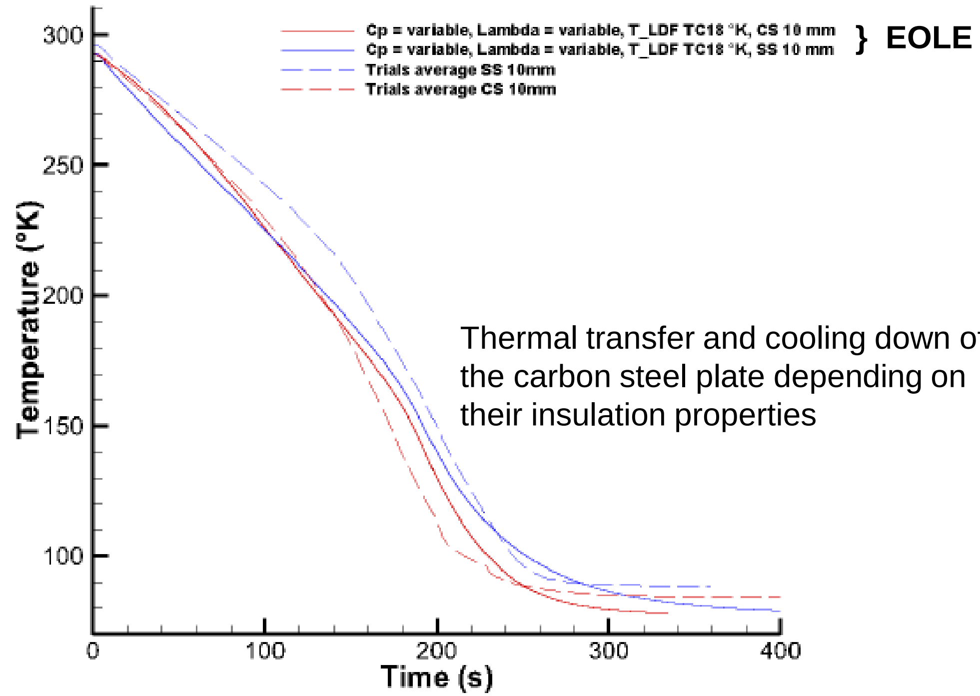
Experiment

CFD

EOLE validation – thermal transfer

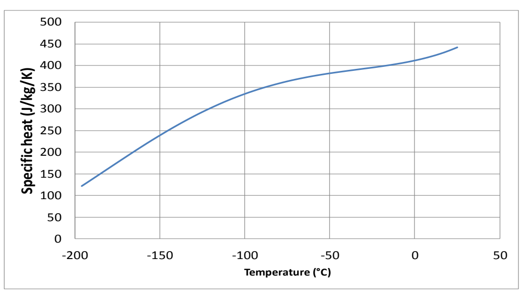
- Temperature across a carbon / stainless steel plates

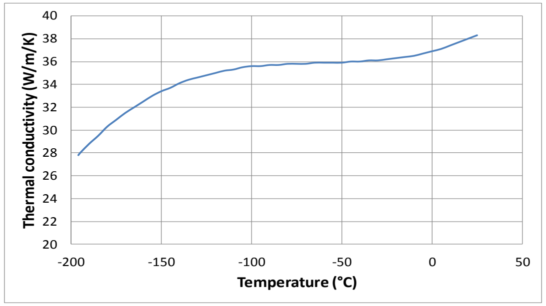




T probe

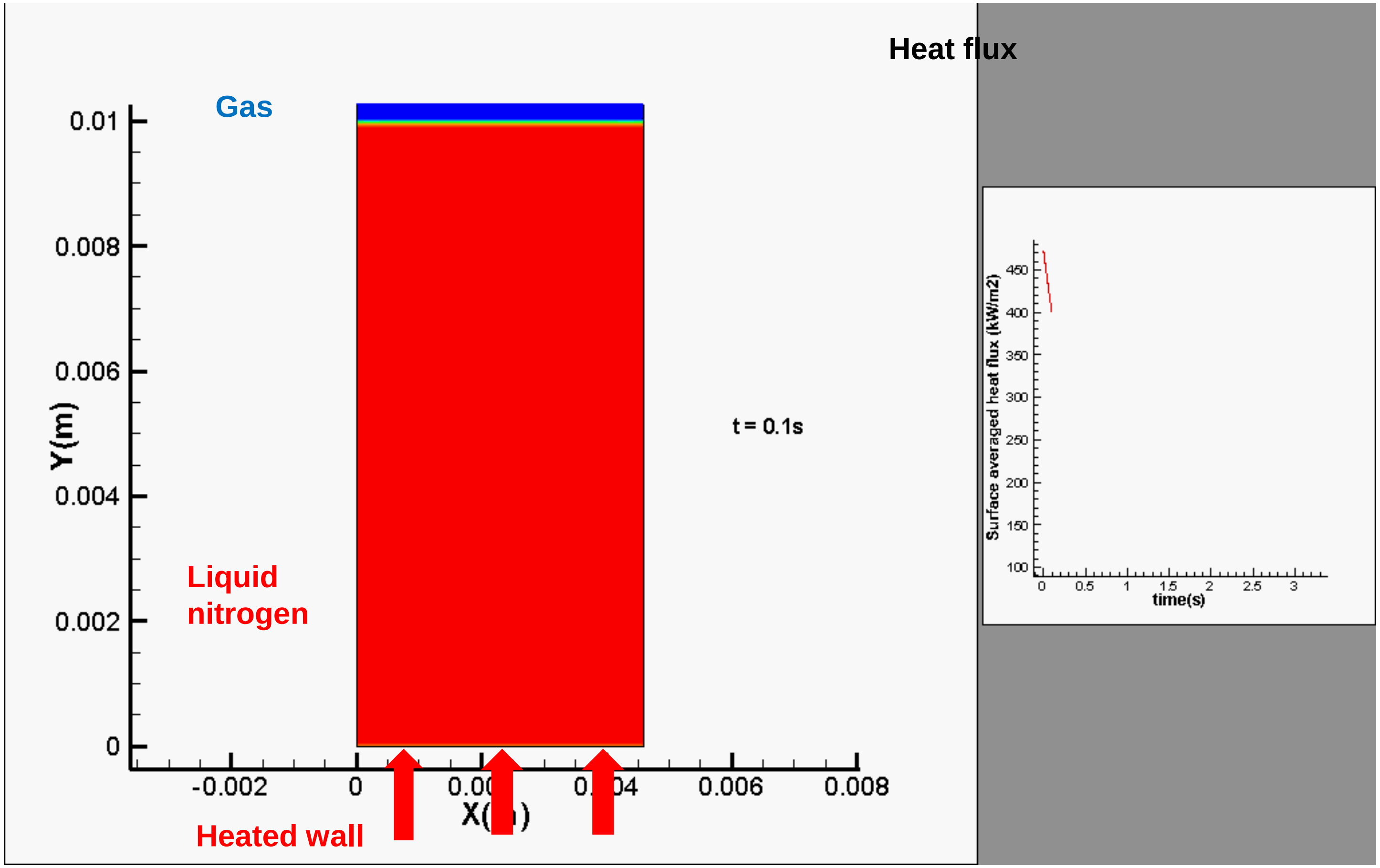
Thermal transfer and cooling down of the carbon steel plate depending on their insulation properties





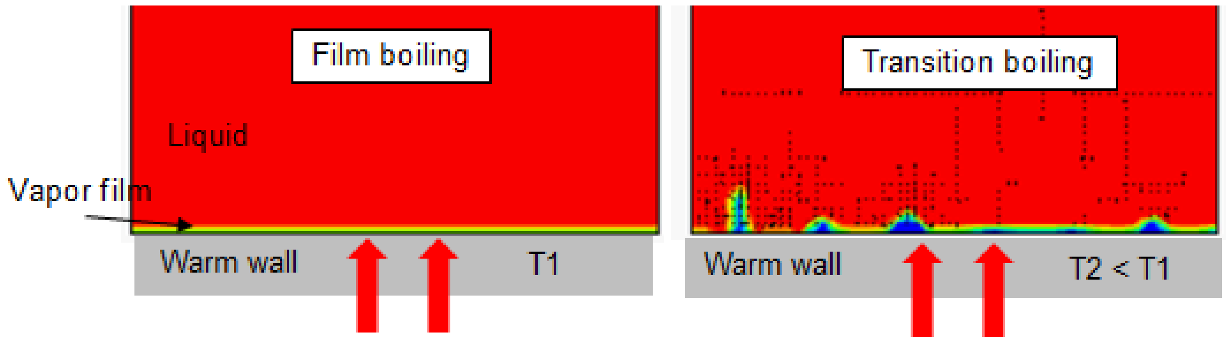
EOLE validation – boiling curve

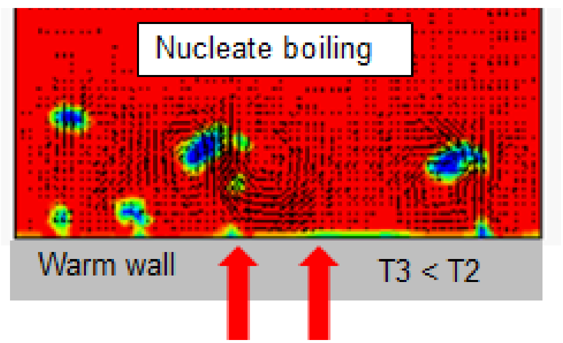
- Fluid / solid thermal transfer and vaporization

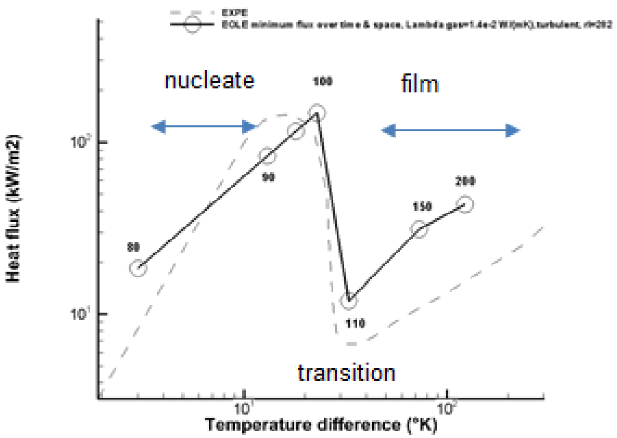


EOLE validation – boiling curve

- Fluid / solid thermal transfer and vaporization







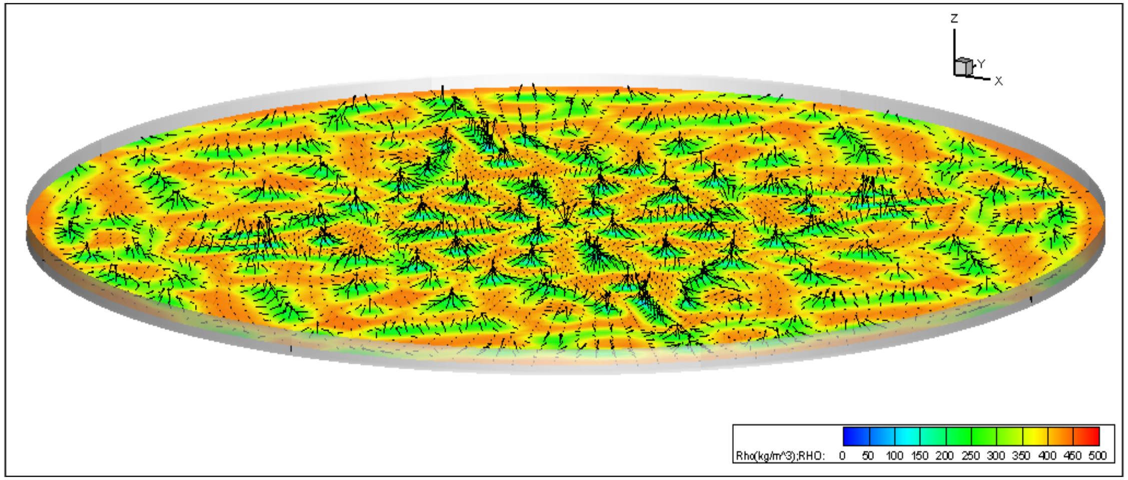
CFD computed boiling curve

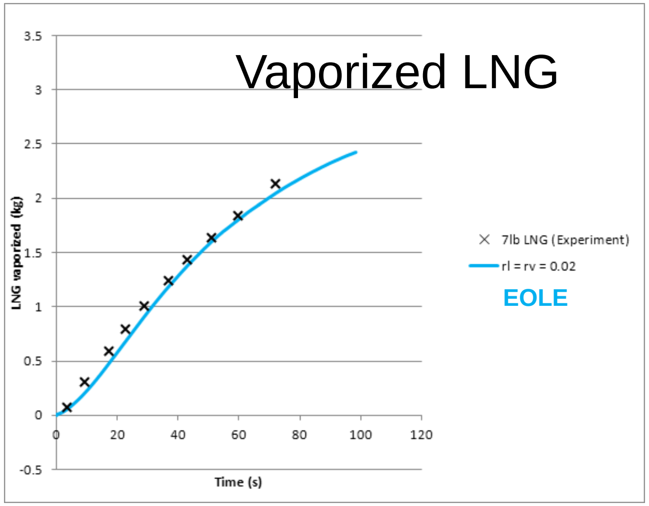
EOLE validation - vaporization

Experimental set-up : US Bureau des Mines

Hazards of LNG spillage in marine transportation

- LNG vaporization on solid substrate (static case)

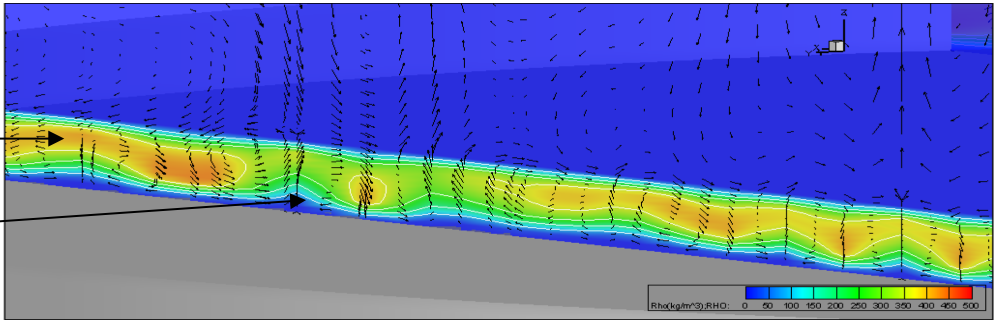




- Film boiling

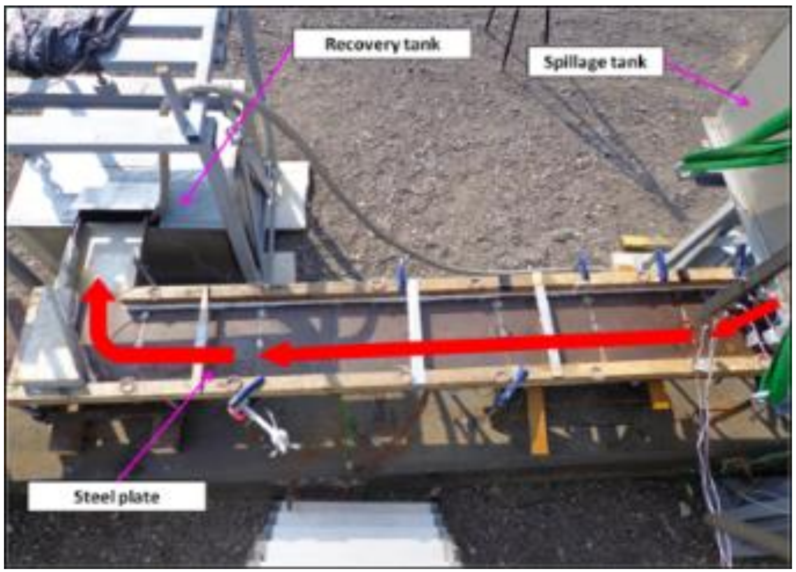
Natural convection in LNG layer

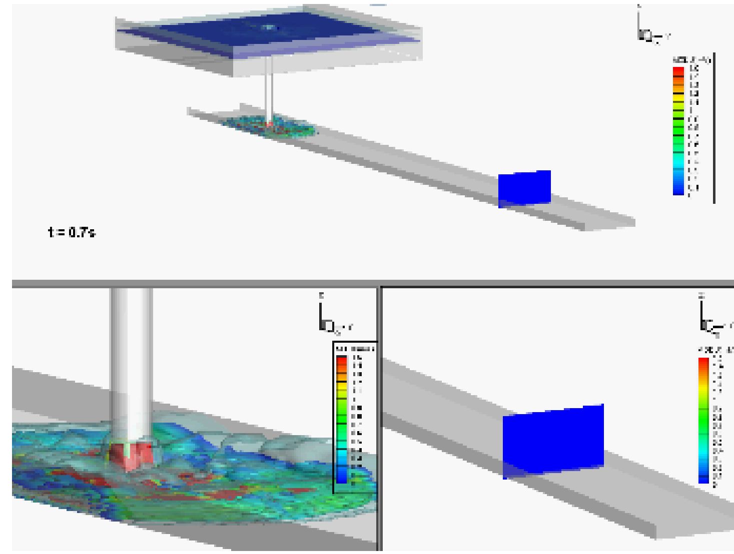
Film boiling (vapor)

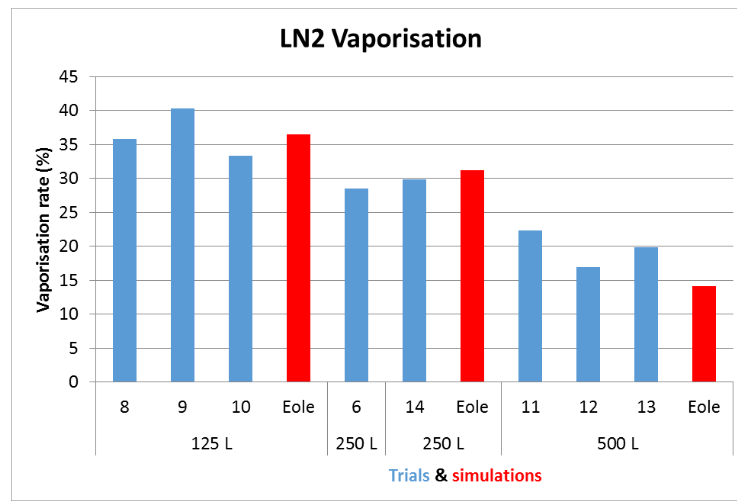


EOLE validation - pool

- LN2 pool spreading and vaporization
  - on solid substrates



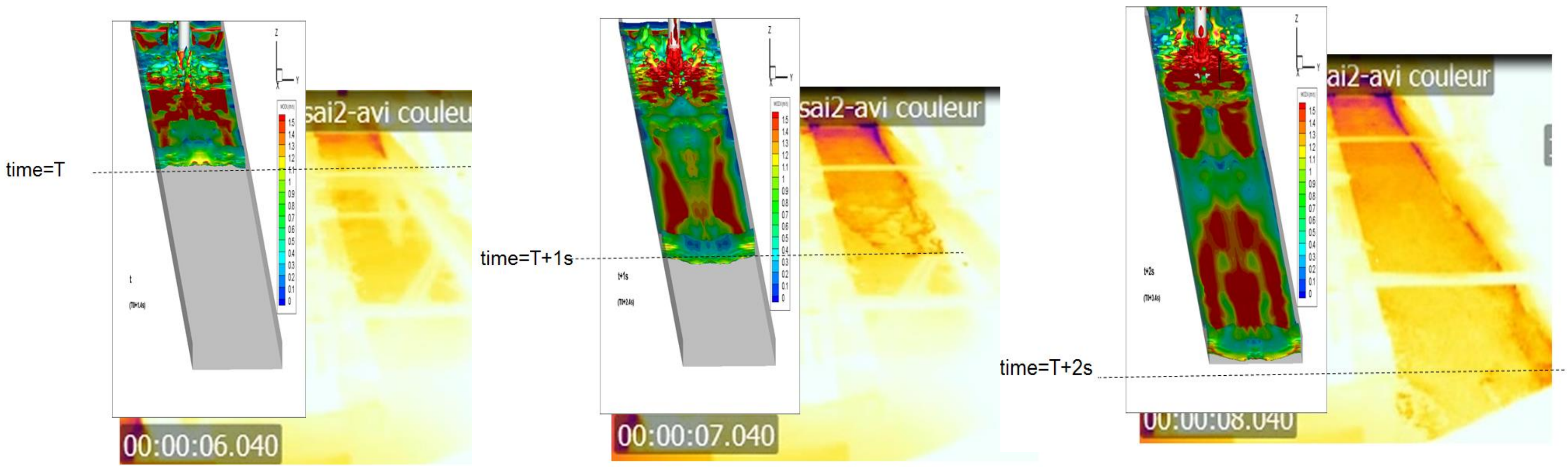




Vaporization rate

EOLE validation - pool

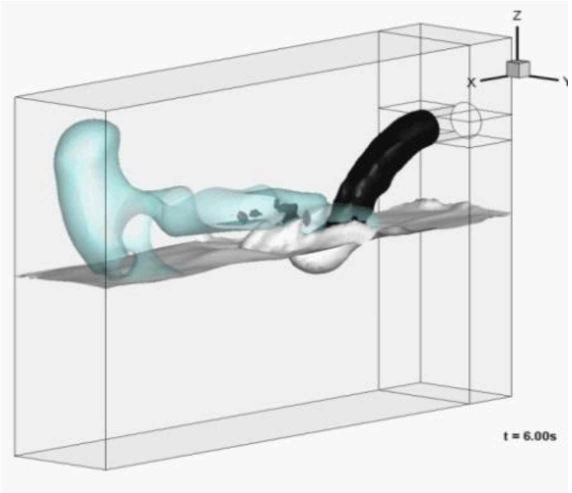
- LN2 pool velocity



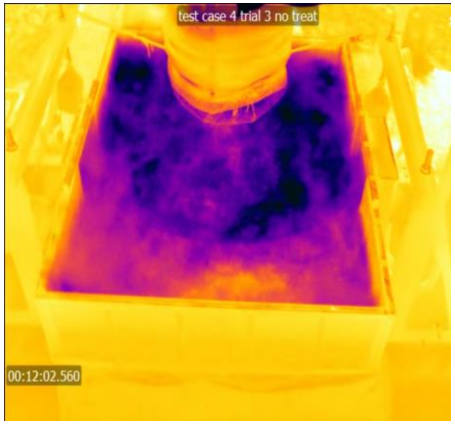
EOLE validation – cryogenic liquid / water

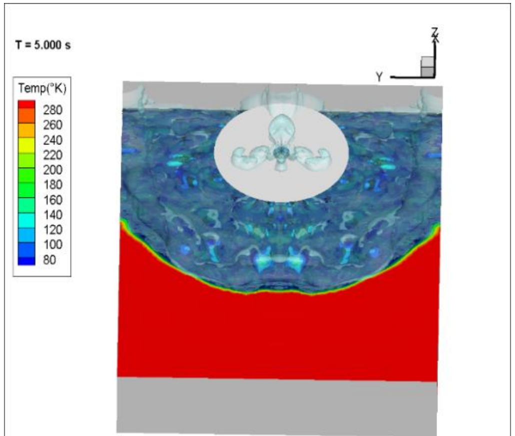
- LN2 pool spreading on seawater

Academic



Experiment

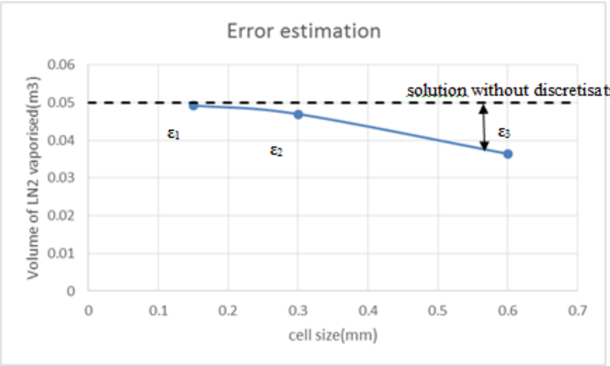




CFD

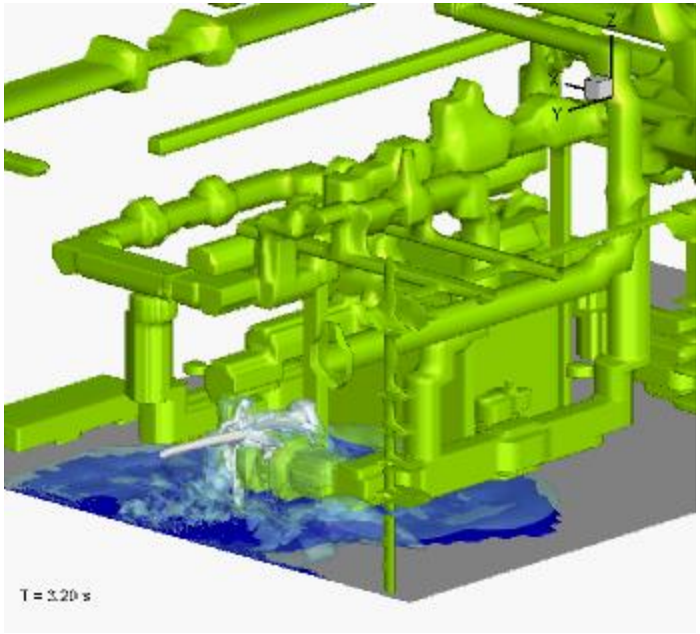
EOLE : a qualified CFD software for LNG

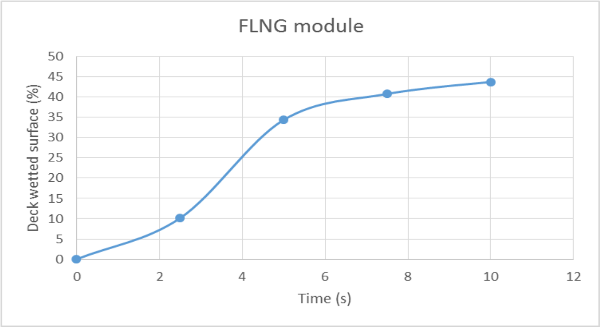
- Verification and Validation (V&V) for EOLE qualification



Vaporization estimation error – Mesh sensitivity

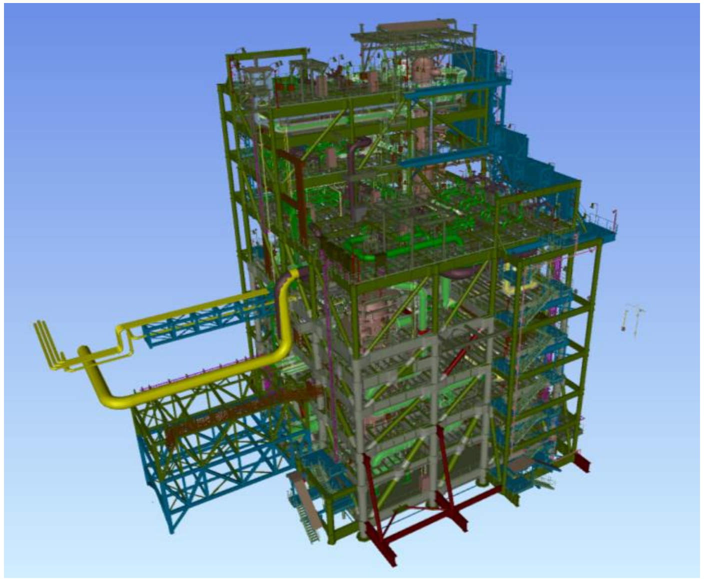
- Industrial application : FLNG module

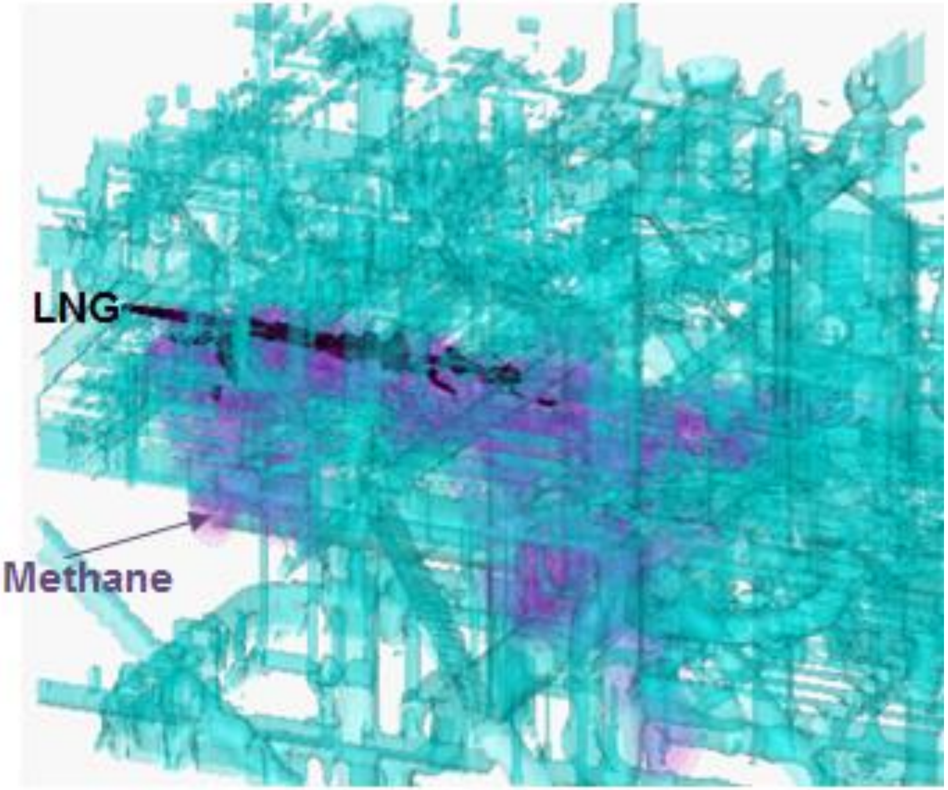




Evolution of deck wetted surface percentage over time

Example of industrial application





Conclusions

- **LNG spillage and interactions with structures**
  - An overall complex physical problem
- **A step-by-step validation methodology**
  - Two-phase jet, pool spreading, cryogenic fluid / solid (or water) thermal transfer, vaporization,…
- **Qualification of the numerical model based on V&V approach**
- **EOLE : a powerful validated tool for cryogenic fluid problems**