GL Noble Denton

DDT – Experiments revisited and new insight

- Part II - Modelling

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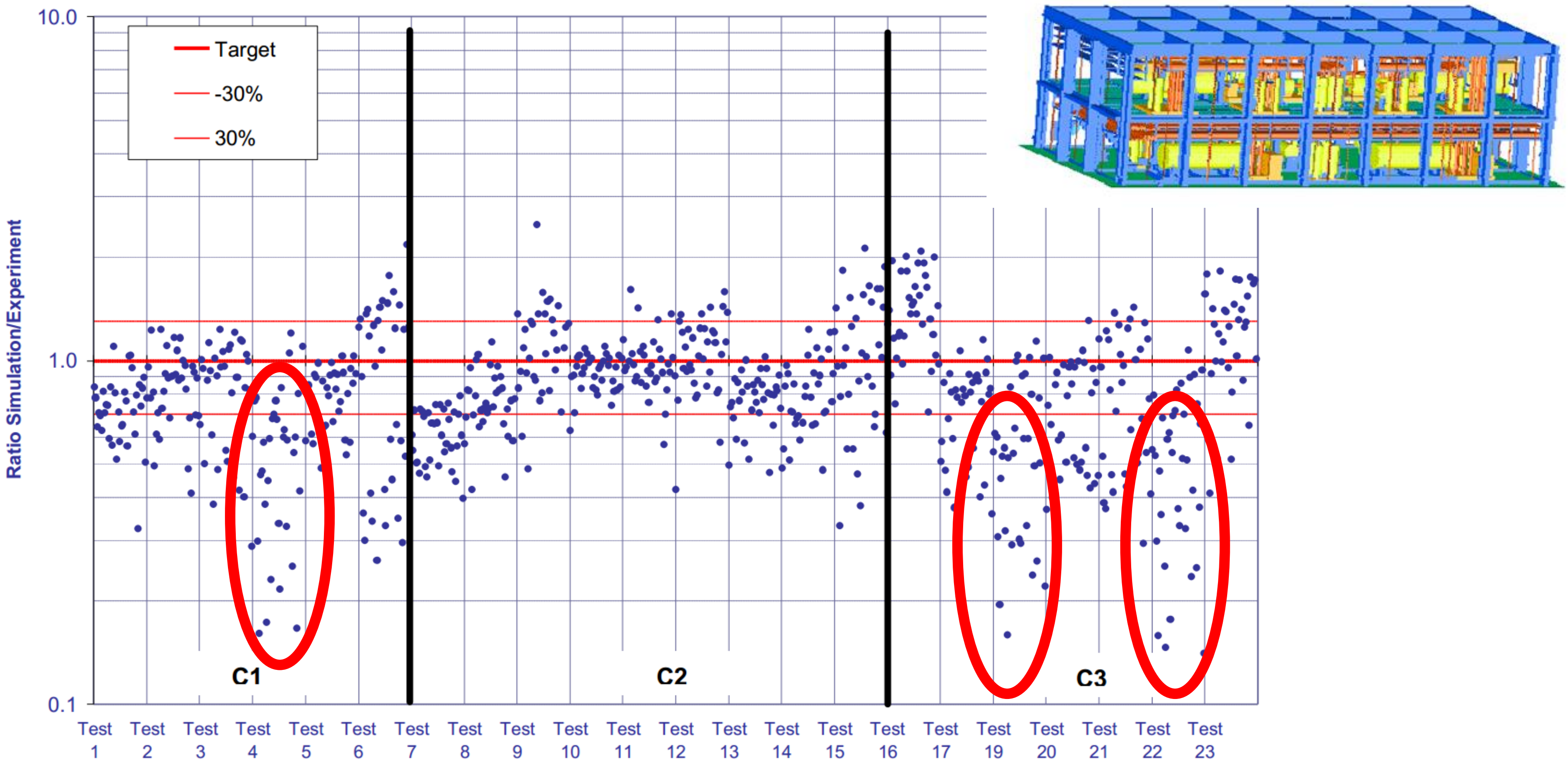
UKELG meeting Cardiff July 10, 2013

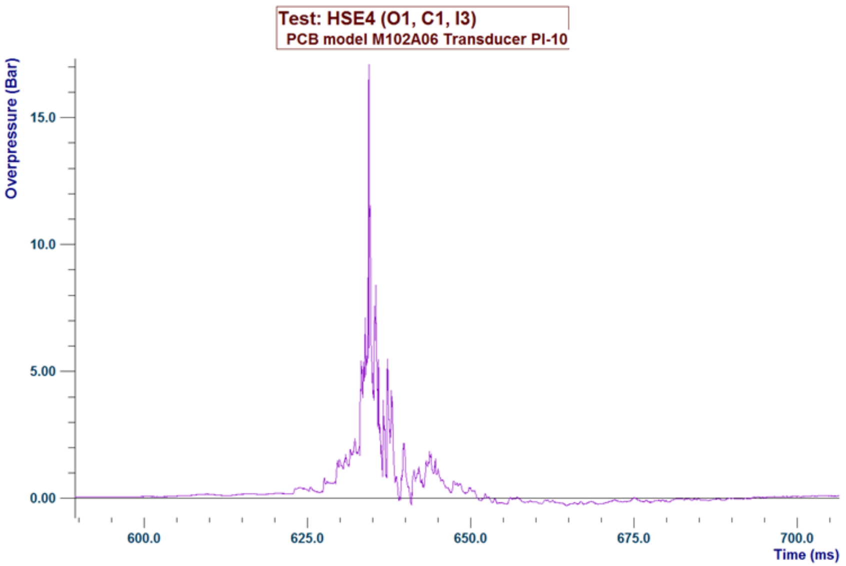
FLACS validation & pushing limits – Obsession for 20 years:

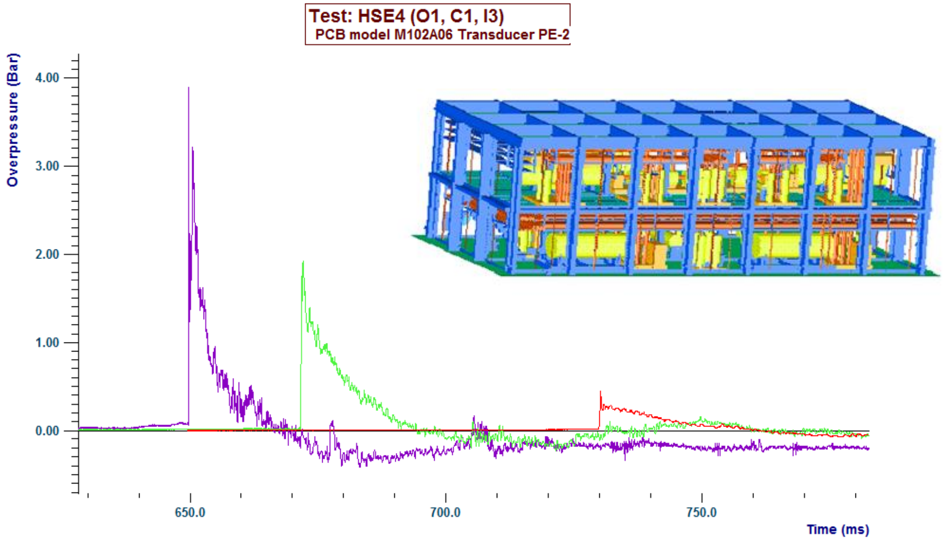
- Good results in various fields, e.g. dispersion & explosion for hydrocarbons, hydrogen, LNG, dust, explosives, blast, QRA-methods and more
- Sometimes deviation to tests could not be understood



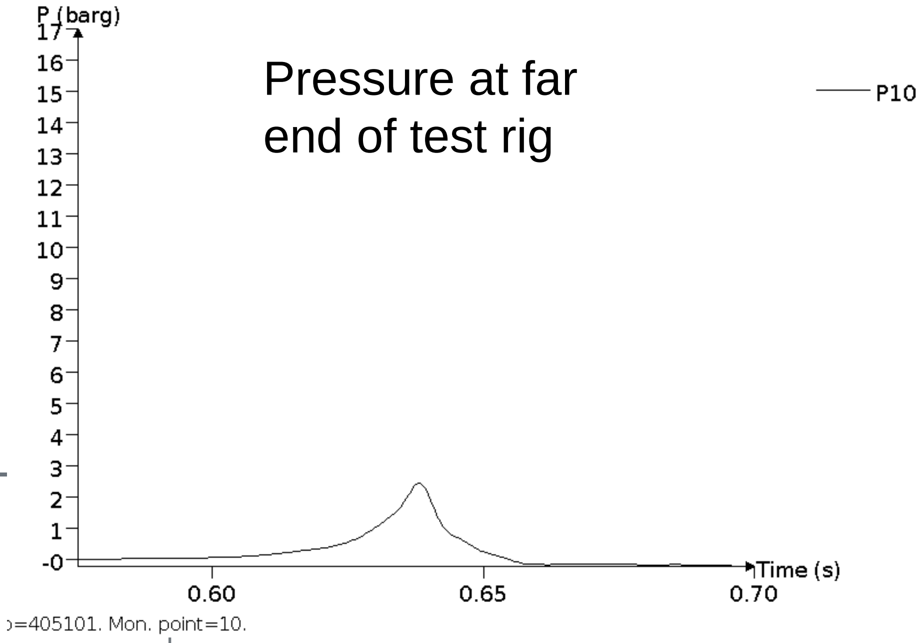
Validation against full scale experiments 1997-98, e.g. HSE Phase 3A test 4, 19 and 22

HSE Phase 3A Test 4 blast severely underpredicted

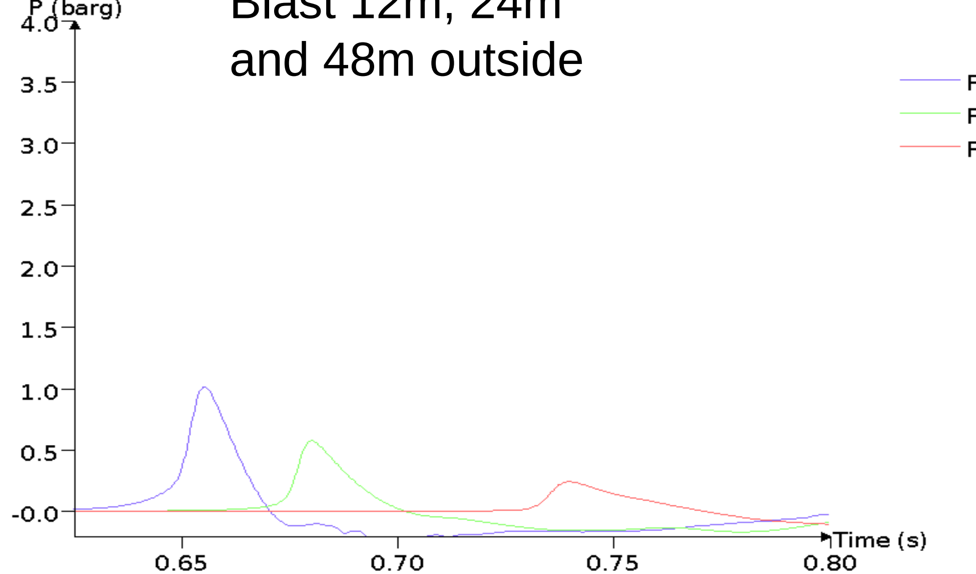




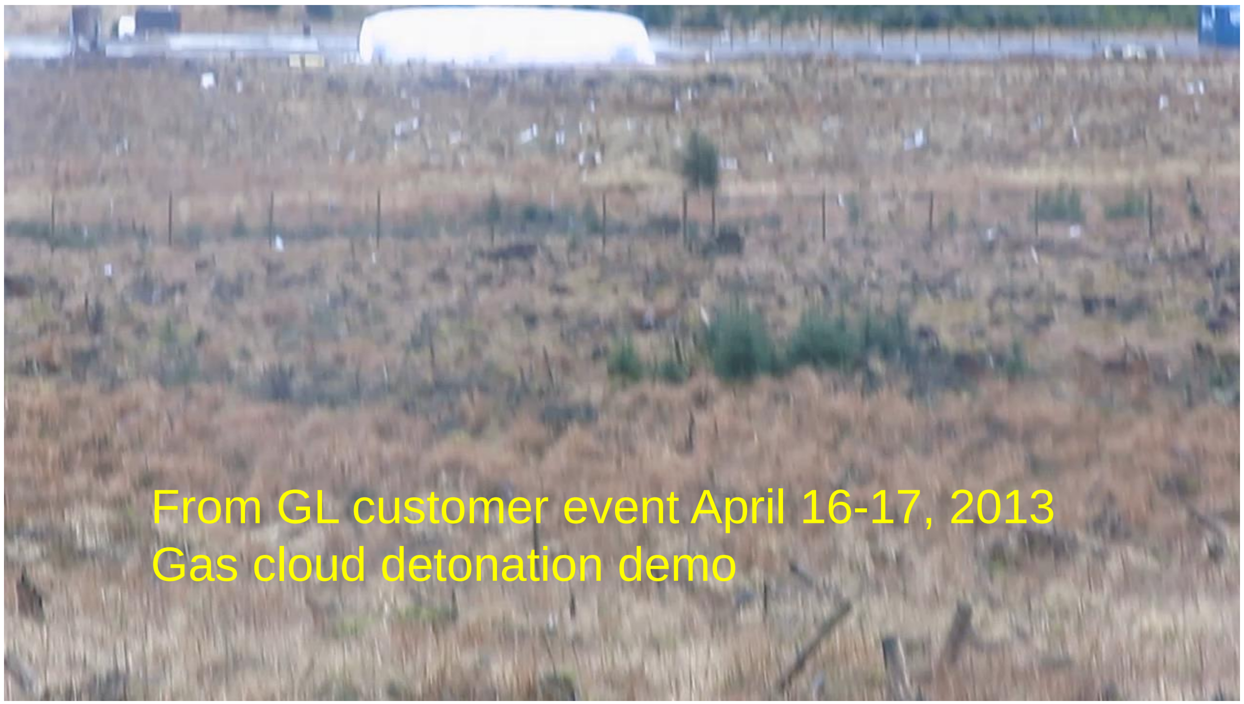
Pressure at far end of test rig



Blast 12m, 24m and 48m outside



Detonation "makes a difference"



Onshore Explosion Studies

Usually focus to **minimize blast loads on control rooms** or other buildings

- API RP 752 and Seveso-II : Blast curves + simple dispersion "industry practice"

MANAGEMENT OF HAZARDS ASSOCIATED WITH LOCATION OF PROCESS PLANT PERMANENT BUILDINGS API RECOMMENDED PRACTICE 752 THIRD EDITION	3.10 **maximum credible event** **MCE** A hypothetical explosion, fire or toxic event that has the potential maximum consequence to the occupants of the building under consideration from among the major scenarios evaluated. The major scenarios are realistic and have a reasonable probability of occurrence considering the chemicals, inventories, equipment and piping design, operating conditions, fuel reactivity, process unit geometry, industry incident history and other factors. Each building may have its own set of MCEs for potential explosion, fire or toxic impacts.

Seveso-II Article 5 **General obligations of the operator**
Member States shall ensure that the operator is obliged to take **all measures necessary** *to prevent major accidents and to limit their consequences for man and the environment.*

Maximum Credible Event (MCE) in focus:

⇒ What is **CREDIBLE**? What is **reasonable probability** of occurrence?

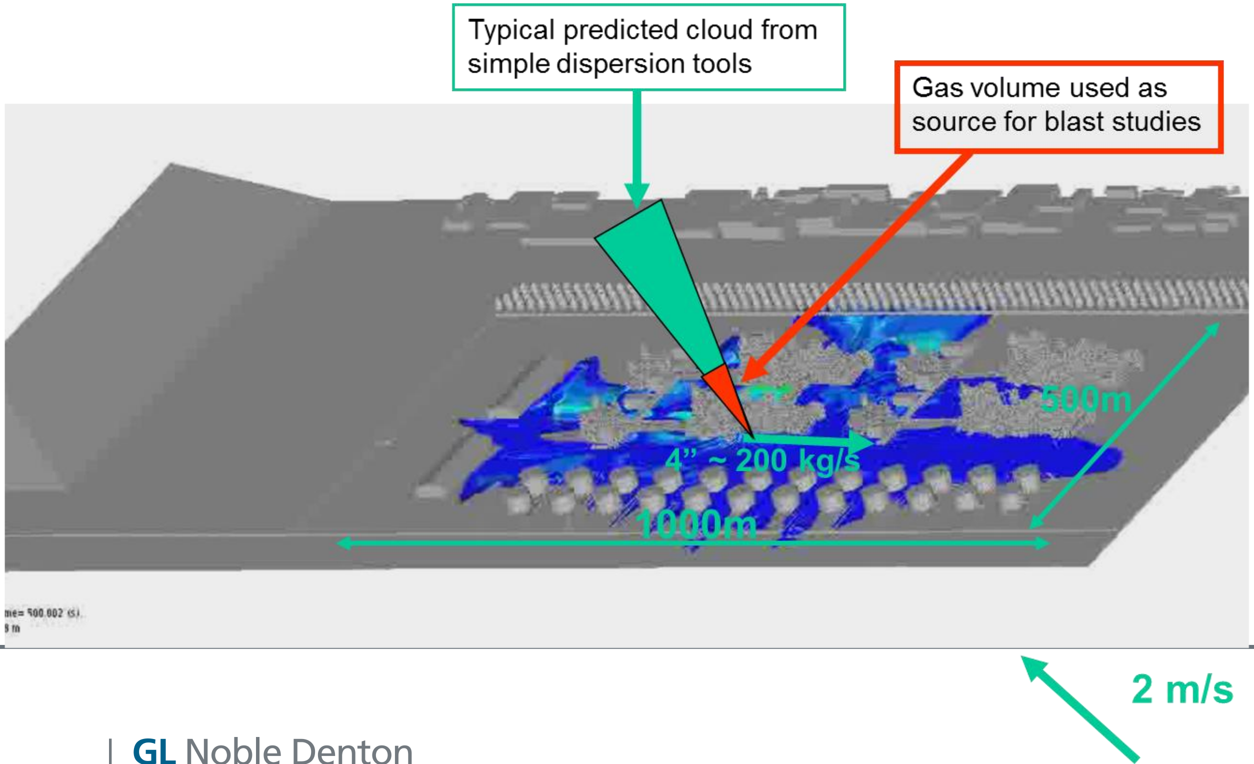
Simplified consequence modeling

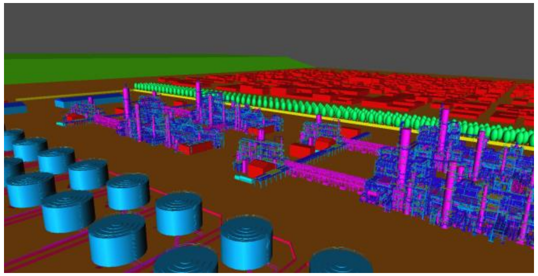
⇒limited mitigation possibilities **AND** no development towards safer design

Dispersion: Potential Underprediction of Cloud Sizes

- Ignoring geometry effects can result in the incorrect identification of relevant risk drivers and also lead to significant under-prediction of relevant vapour cloud sizes
- Selected “credible” leak rates may be arbitrary and not representative for worst-case
- Potentially very non-conservative blast energy estimate based on cloud size/congestion

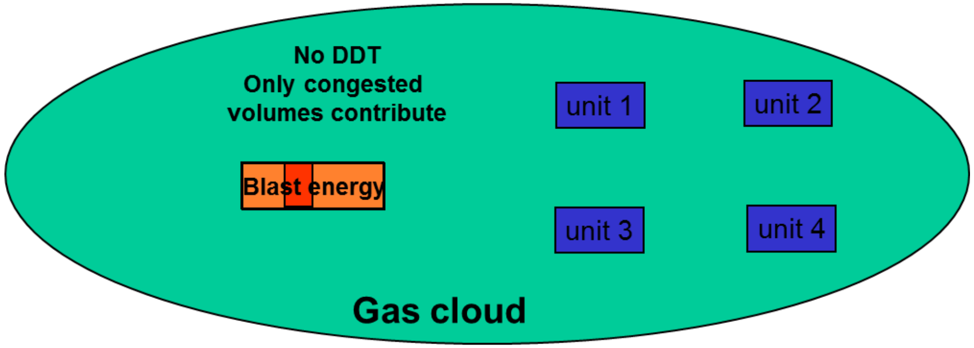
Example: LPG release at a facility

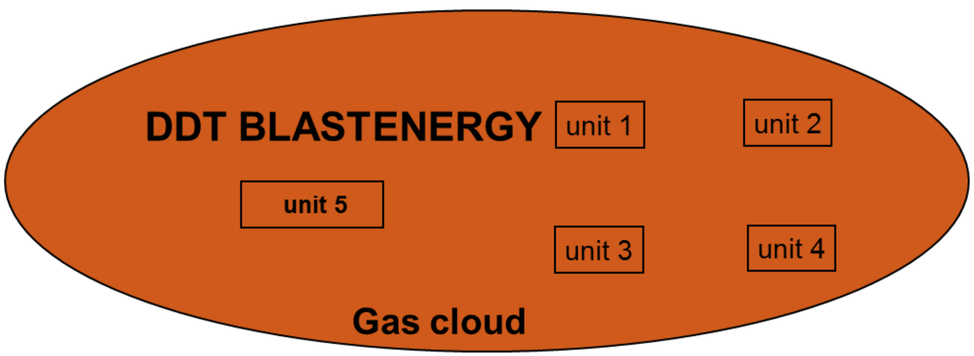




Blast Strength – too low – evaluate whether DDT?

- Blast source strength assumption arbitrary and non-conservative for real scale accidents
- Potentially very non-conservative methods for blast energy based on cloud size/congestion
- Potential for deflagration-to-detonation transition (DDT) is usually ignored





API RP 752 does not discuss the possibility for DDT at all
DDT seldom considered in Seveso-II studies

DDT may be more likely than industry wants to believe

Some of the recent major accidents likely involved DDTs

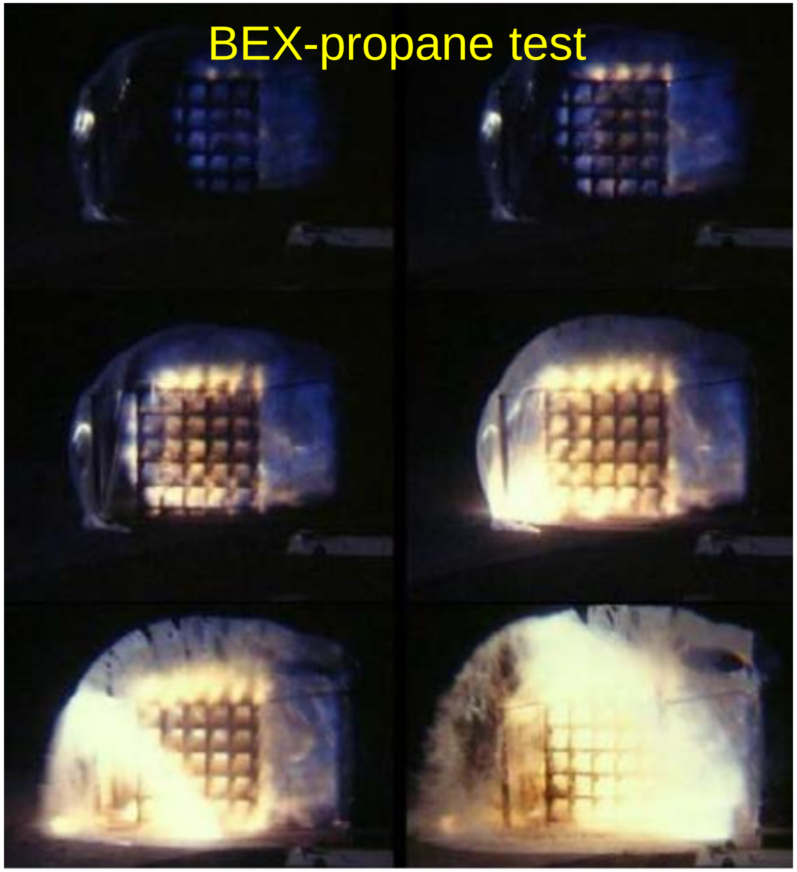
- Buncefield 2005
- Toronto 2008
- Jaipur 2009

And there were probably many more

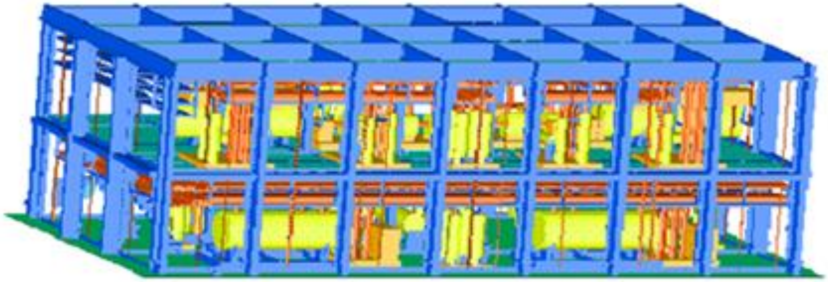
DDT may be more likely than industry wants to believe

DDT seen in several large scale experiments, for instance at GL Spadeadam test site

- 45m enclosure with pipes (1980s)
- BEX-experiments (~1990)
- Merge experiments (1993-1996)
- Buncefield tree tests (2012-2013)
- HSE Phase 3A tests? (Natural gas)



HSE Phase 3A rig – 28m x 12m x 8m



Can we efficiently predict/model DDT?

FLACS focus 1990s was oil platforms 0.3-1.0 bar => major problem **DDT not of interest**

FPSOs, FLNGs, onshore facilities … => DDT starts to become more interesting

Since 2006 or so we developed criteria to predict potential for DDT (DPDX parameter)

DDT consequences can not be modelled **…. OR**?

Other weaknesses with FLACS for FLNG/FPSO/onshore:

- Flames accelerate too much after "safety gaps"

  ⇒ **weakness, work-around exists**
- Strong far-field pressures smeared and underpredicted

  ⇒ **modified guidelines reduce problem**

  (cn-file to reduce time-step strongly after explosion)

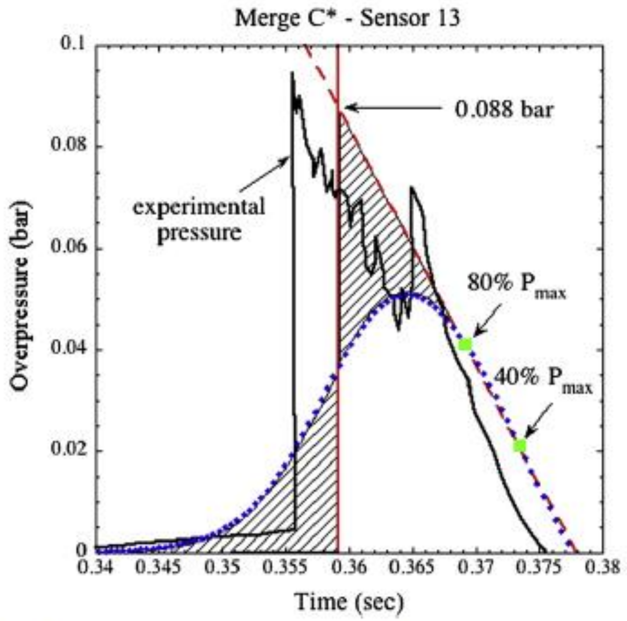


Fig. 21 Proposed method for post-processing FLACS far-field pressures (strong explosions).

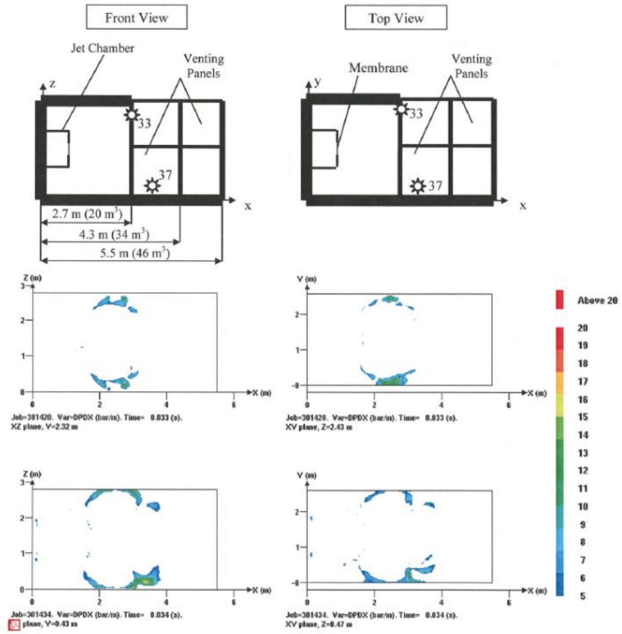
FLACS DDT criteria – initially for developed for hydrogen

Middha & Hansen paper from LP 2006 – DPDX criteria presented first time:

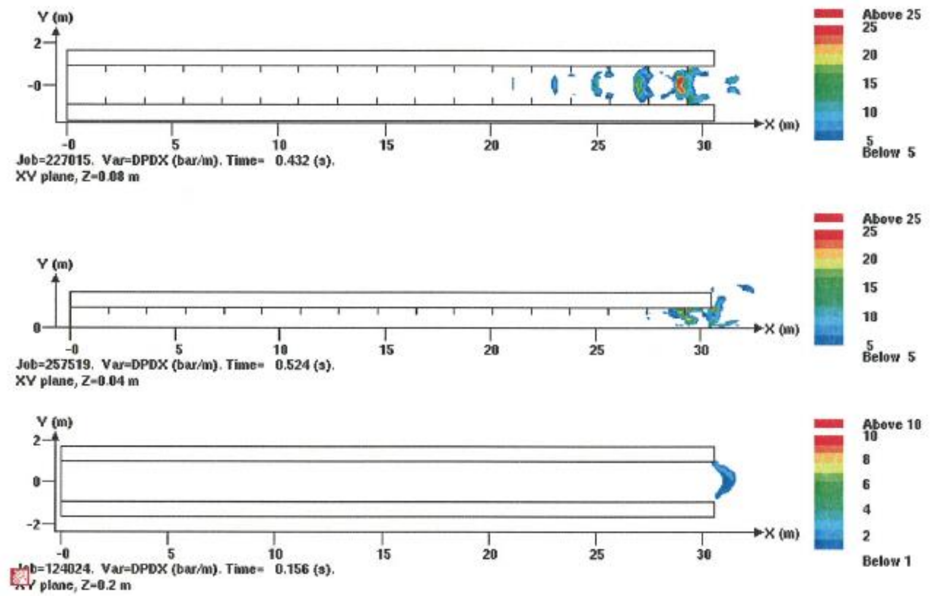
1 DPDX- criterion: Spatial/normalized pressure gradient in flame front

0.5-5 => Maybe DDT > 5 => Likely DDT

2 "Hotspot" region must be large enough to propagate detonation (~10 x 10 λ ?)



Koper facility (Dorofeev)



Sandia FLAME facility tests with DDT

Evaluated against significant number of DDT tests, with quite good precision

FLACS DDT criteria – also working for other gases

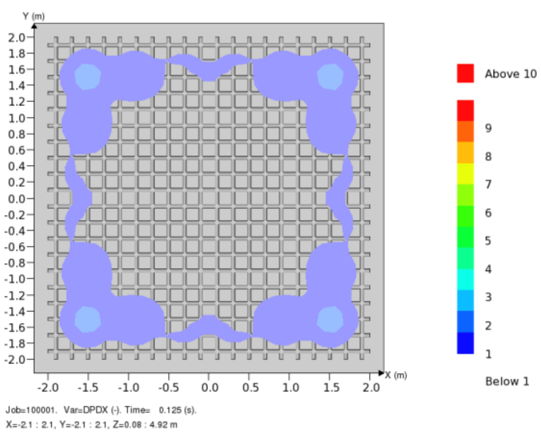
MERGE ethylene tests

Baker Risk ethylene tests

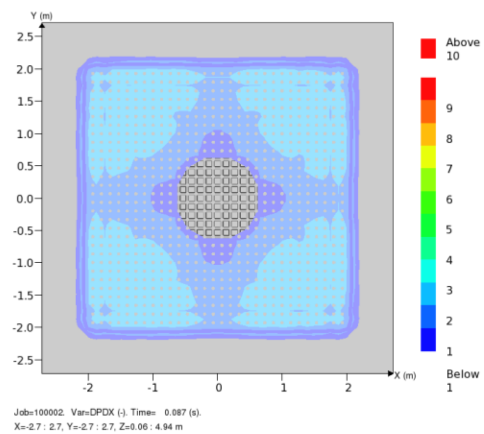
Buncefield propane tests

Table 1: Overview of British Gas MERGE Experiments

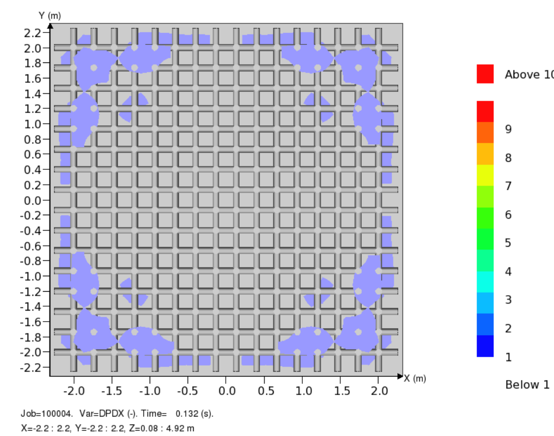
Test	Number of pipes	Pipe diameter	Scale
MERGE-A	20 x 20 x 10	4.3 cm	Medium ($45m^3$)
MERGE-B	30 x 30 x 15	4.1 cm	Medium ($45m^3$)
MERGE-C	10 x 10 x 5	8.6 cm	Medium ($45m^3$)
MERGE-D	16 x 16 x 8	8.2 cm	Medium ($45m^3$)



Merge A: DPDX max = 3



Merge B: DPDX max = 9



Merge D: DPDX max = 4

DDT for 3 out of 4 MERGE ethylene tests (A, B and D)

Also used for consulting work to evaluate DDT potential for onshore sites

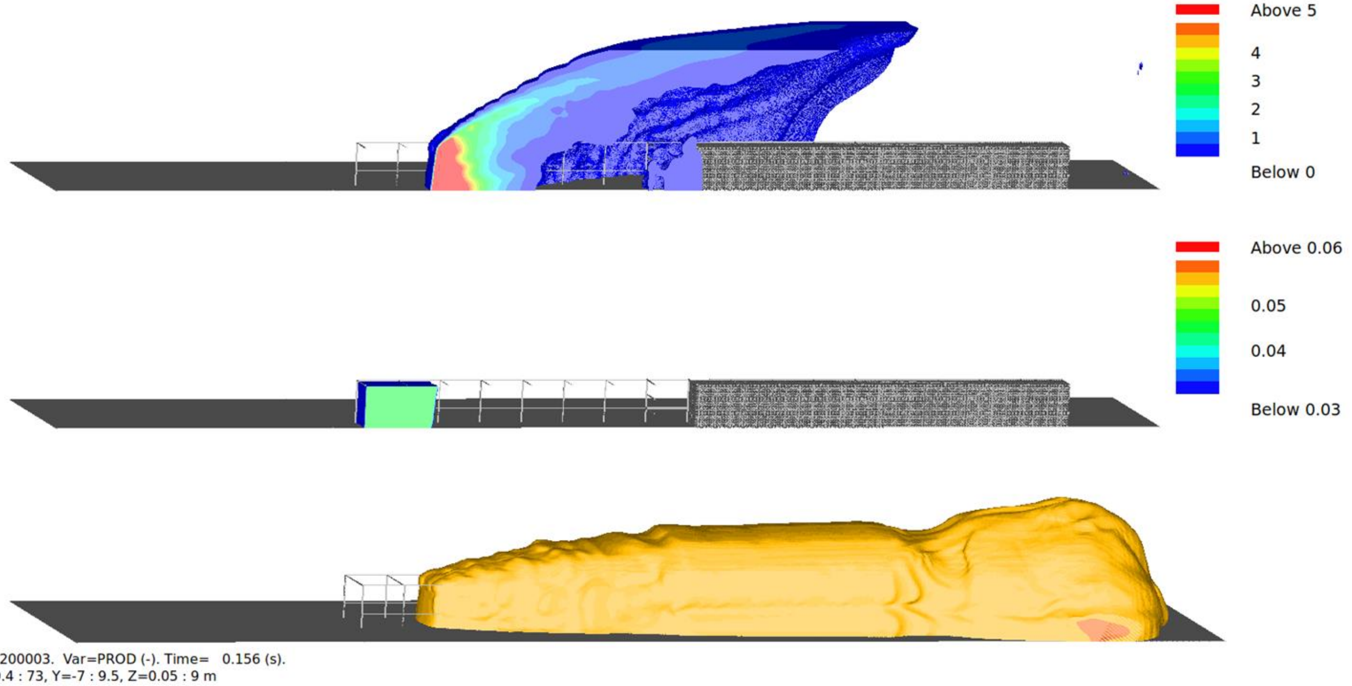
What about modelling of DDT and detonations?

Access to lots of DDT test data at GL

Could FLACS parameters be "tweaked" to predict DDT and detonation consequences?

Approach worked well (accurate predictions) against several experiments, blind simulations of tests not yet performed gave further confidence

Simulation Buncefield DDT test 2

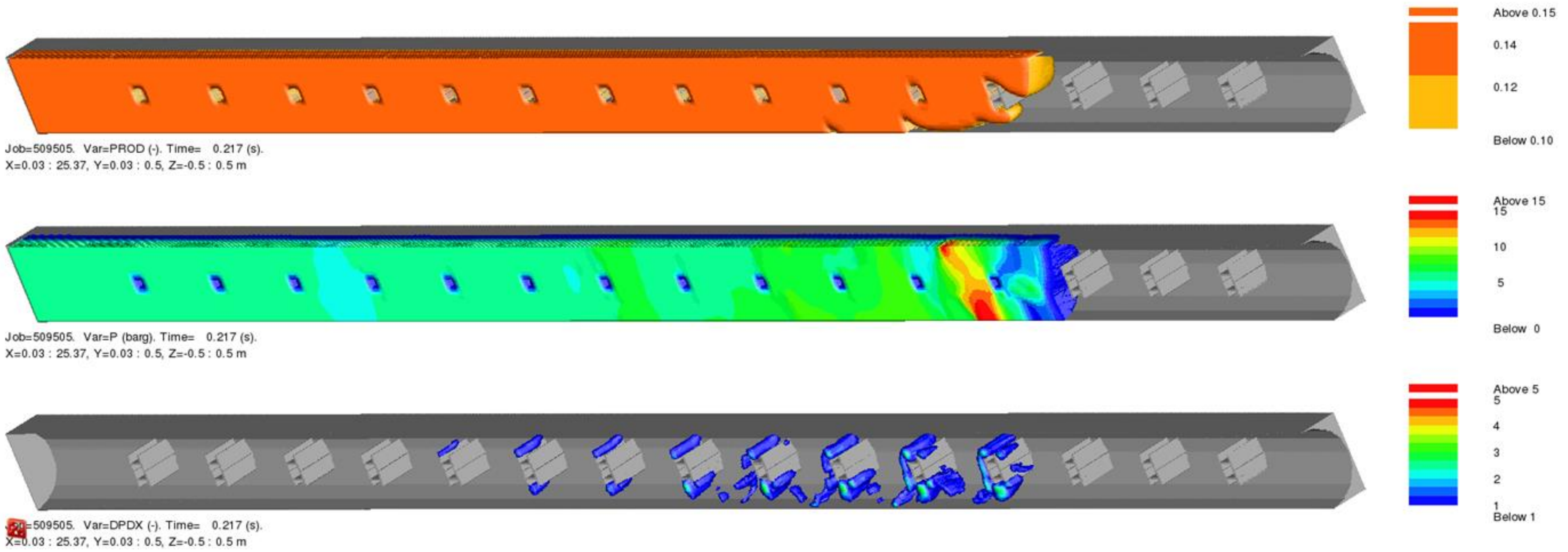


Can DDT happen with natural gas?

Not generally accepted, but some mine explosions have likely seen DDTs

Detonation cell size λ ~0.3m => ~2-4m layer (?) required to propagate a NG detonation

NIOSH performed DDT tests in 73m x 1.05m diameter pipe 2012



As methane is buoyant, confinement may be required (oil platform or FPSO/FLNG-decks)

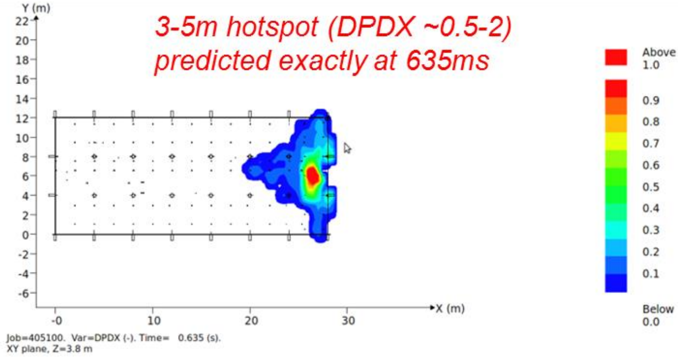
(NG with aerosols or LNG-vapour may be dense and form clouds on the ground)

HSE Phase 3A Test 4 (1998)

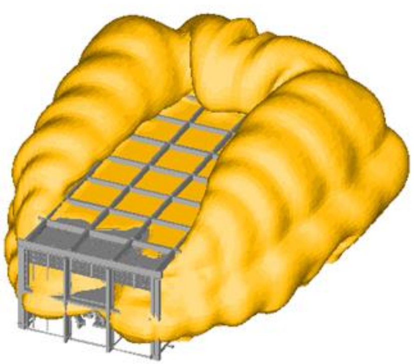
Seriously underestimated with FLACS

New DDT criterion predicts possible DDT at 635ms =>

Simulated as DDT (GL approach to model DDT with FLACS)

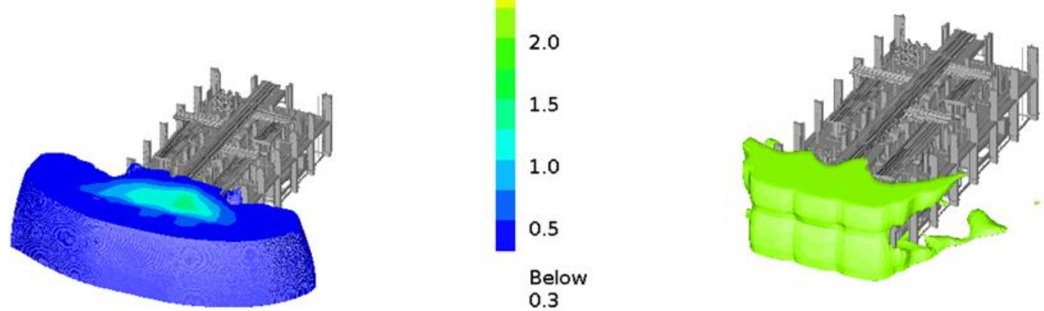


Job	Description
405101	Normal FLACS simulations according to standard guidelines (**Black curves**)
405102	Reduce time step after reaching peak pressure for sharper blast (**Red curves**)
405103	Assume DDT at time=0.635s (**Brown curves, see video1 and video2**)
405104	Assume DDT at time=0.640s (**Blue curves**)

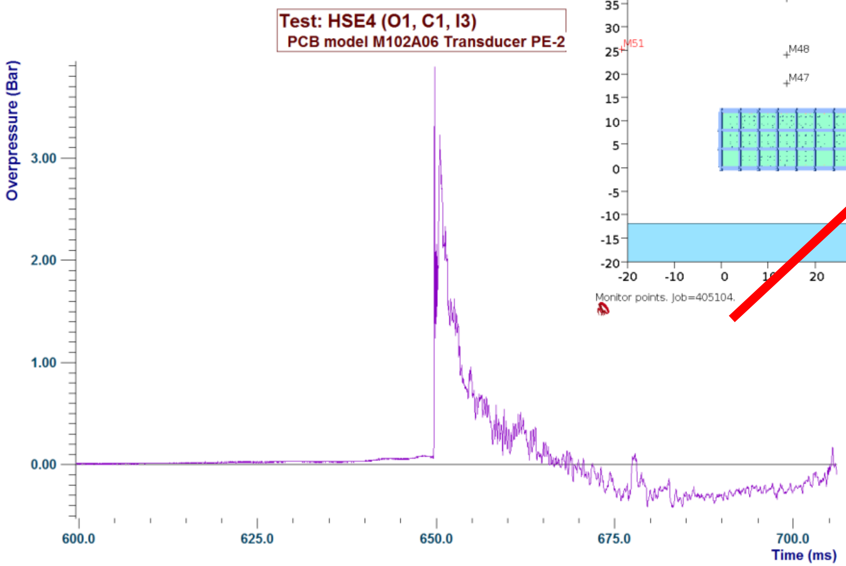


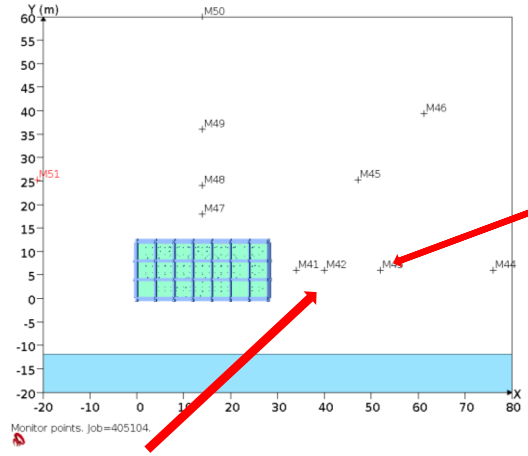
Job=405103. Var=PROD (-). Time= 0.635 (s).
X=-7.8 : 35.799999, Y=-8.8 : 25.799999, Z=0.3 : 14.8 m

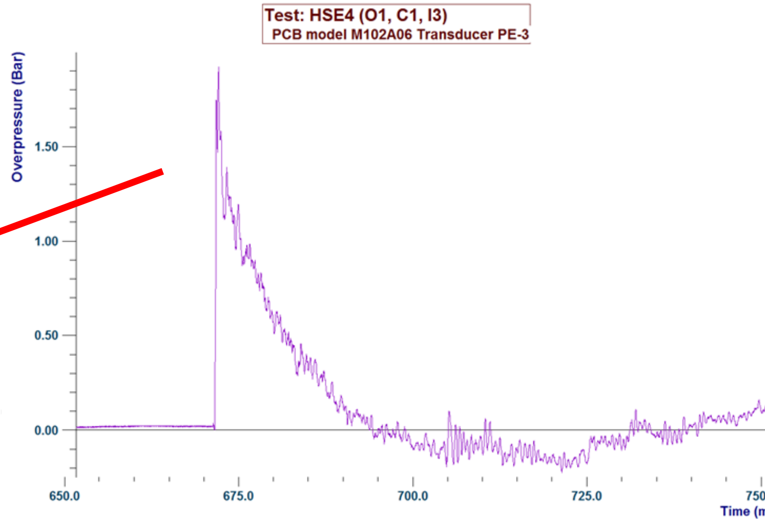
Pre DDT (635 ms)

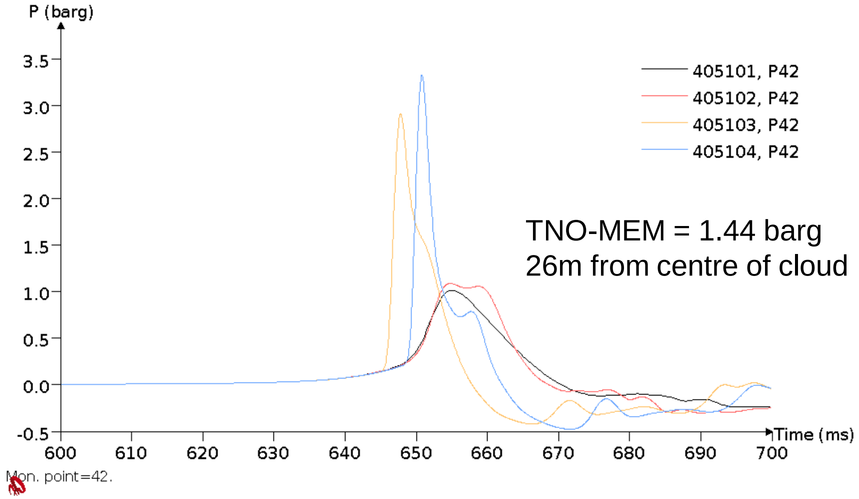


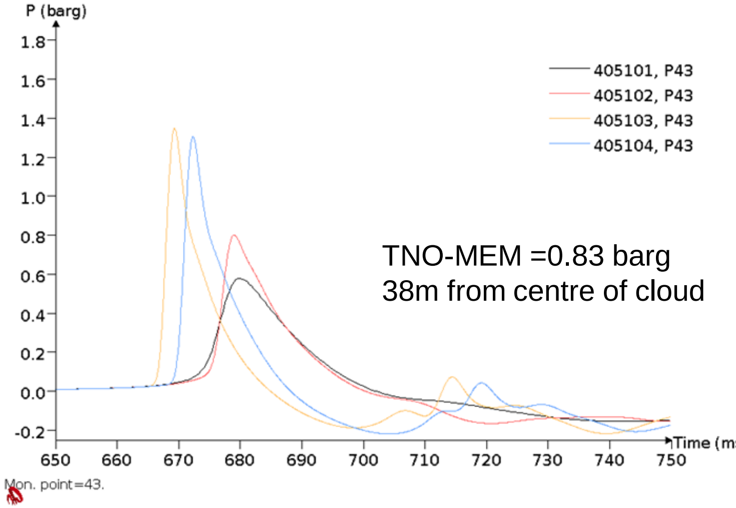
Far field blast sensors 12m & 24m outside



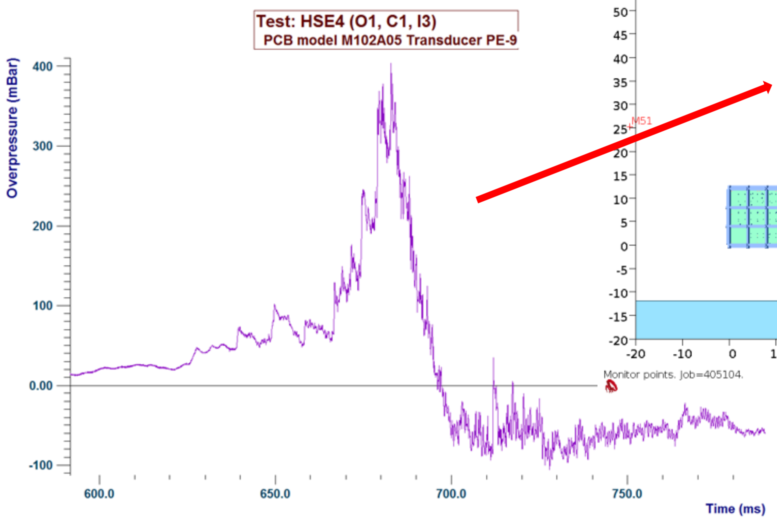


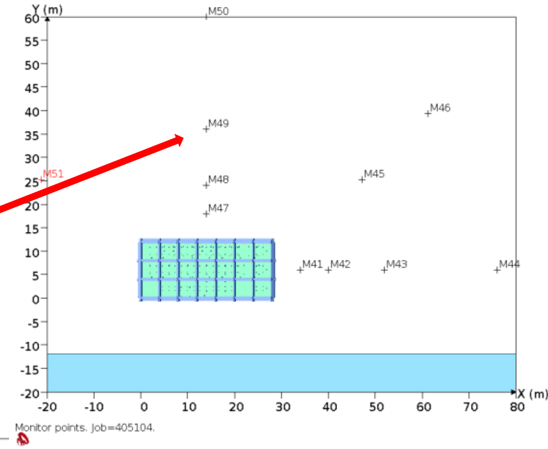




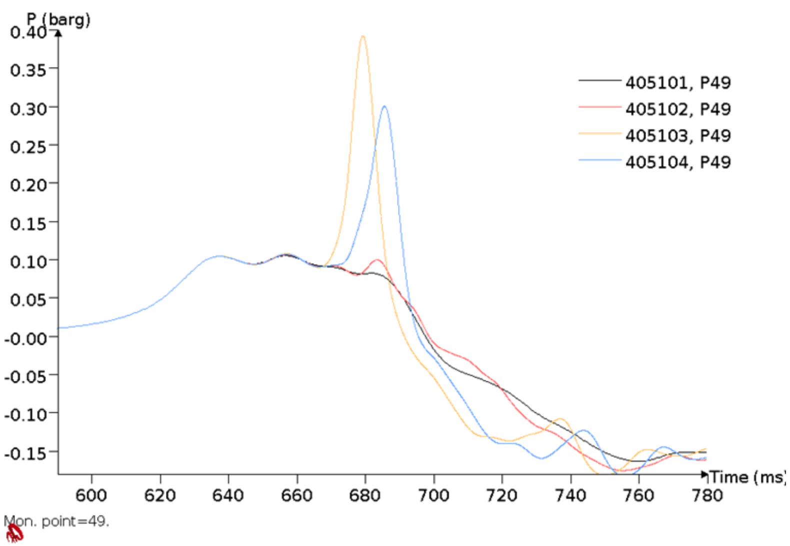


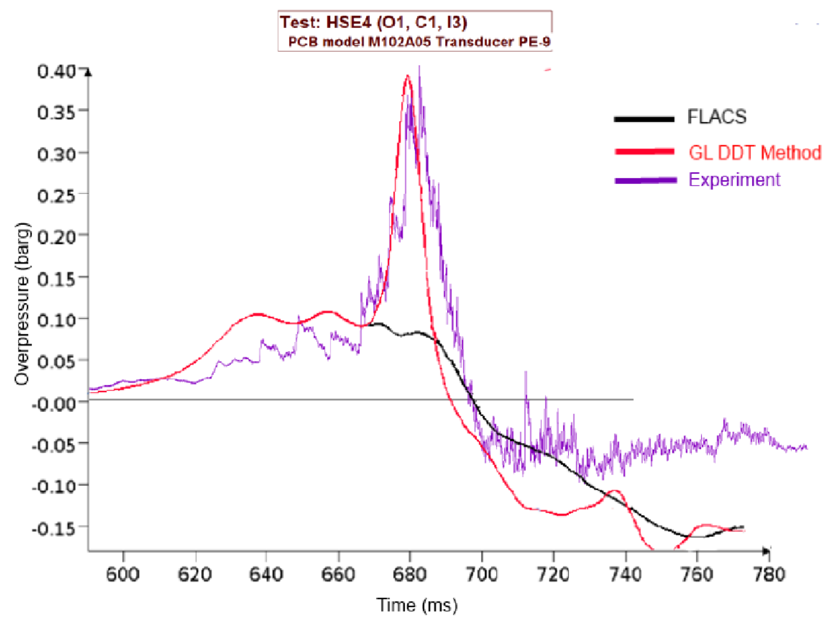
Far field blast sensors 24m N



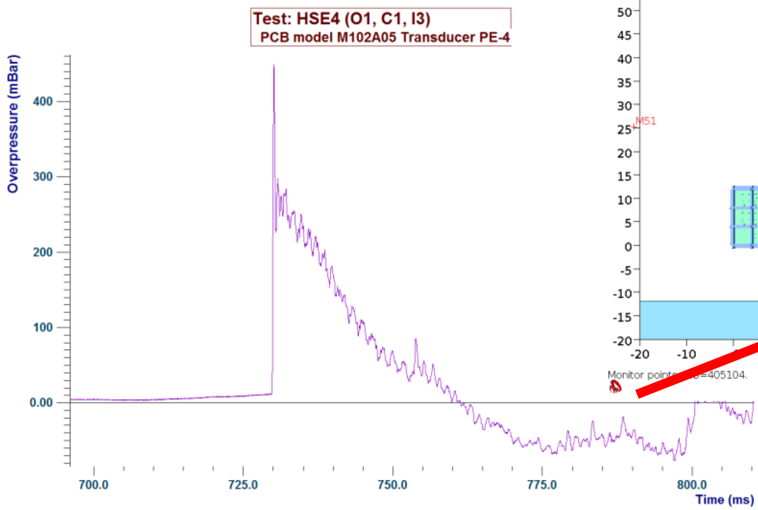


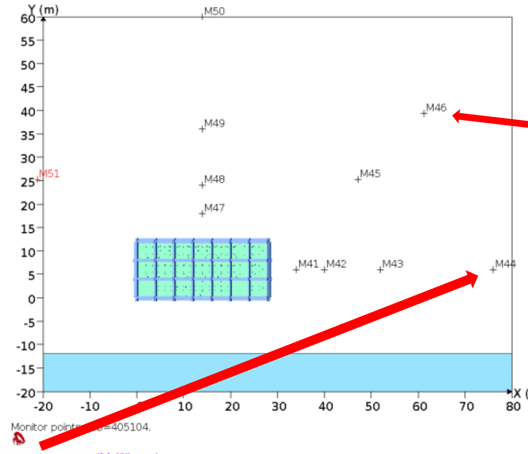
No.	X	Y	Z	Status
41	34.00	6.00	1.00	Open
42	40.00	6.00	1.00	Open
43	52.00	6.00	1.00	Open
44	76.00	6.00	1.00	Open
45	47.20	25.20	1.00	Open
46	61.30	39.30	1.00	Open
47	14.00	18.00	1.00	Open
48	14.00	24.00	1.00	Open
49	14.00	36.00	1.00	Open
50	14.00	60.00	1.00	Open
51	-21.20	25.20	1.00	Out

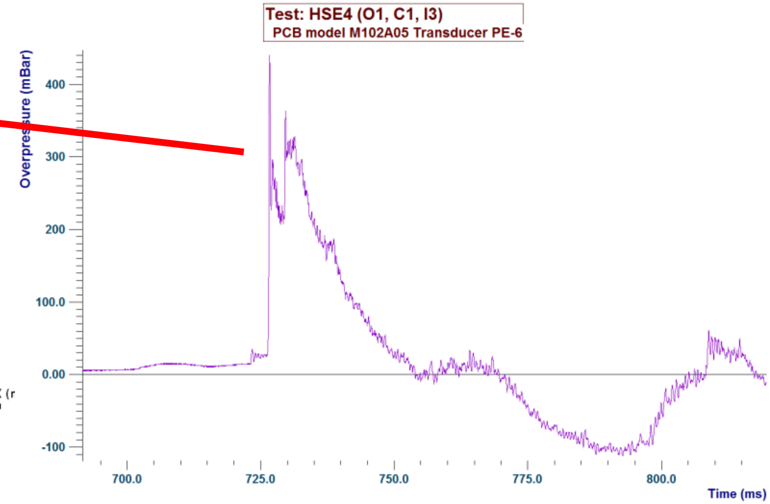


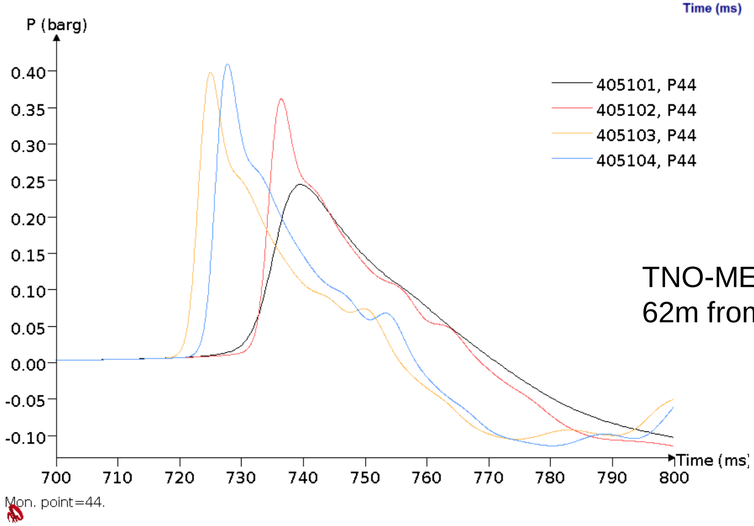


Far field blast sensors 48m East & NE

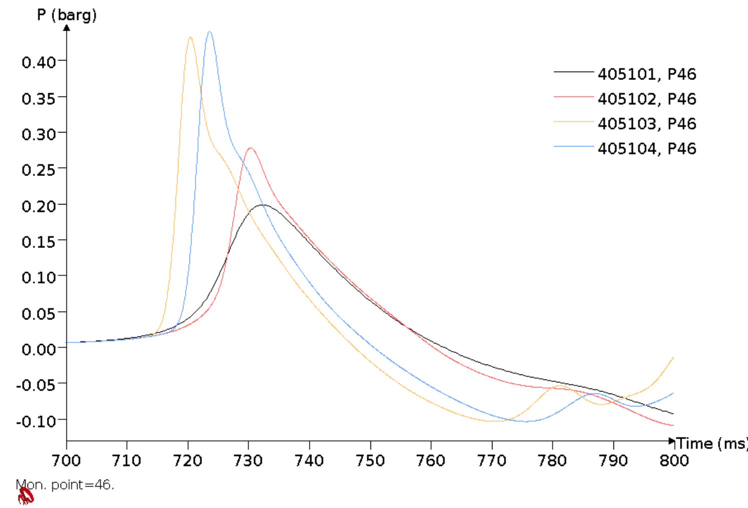








TNO-MEM =0.29 barg
62m from centre of cloud



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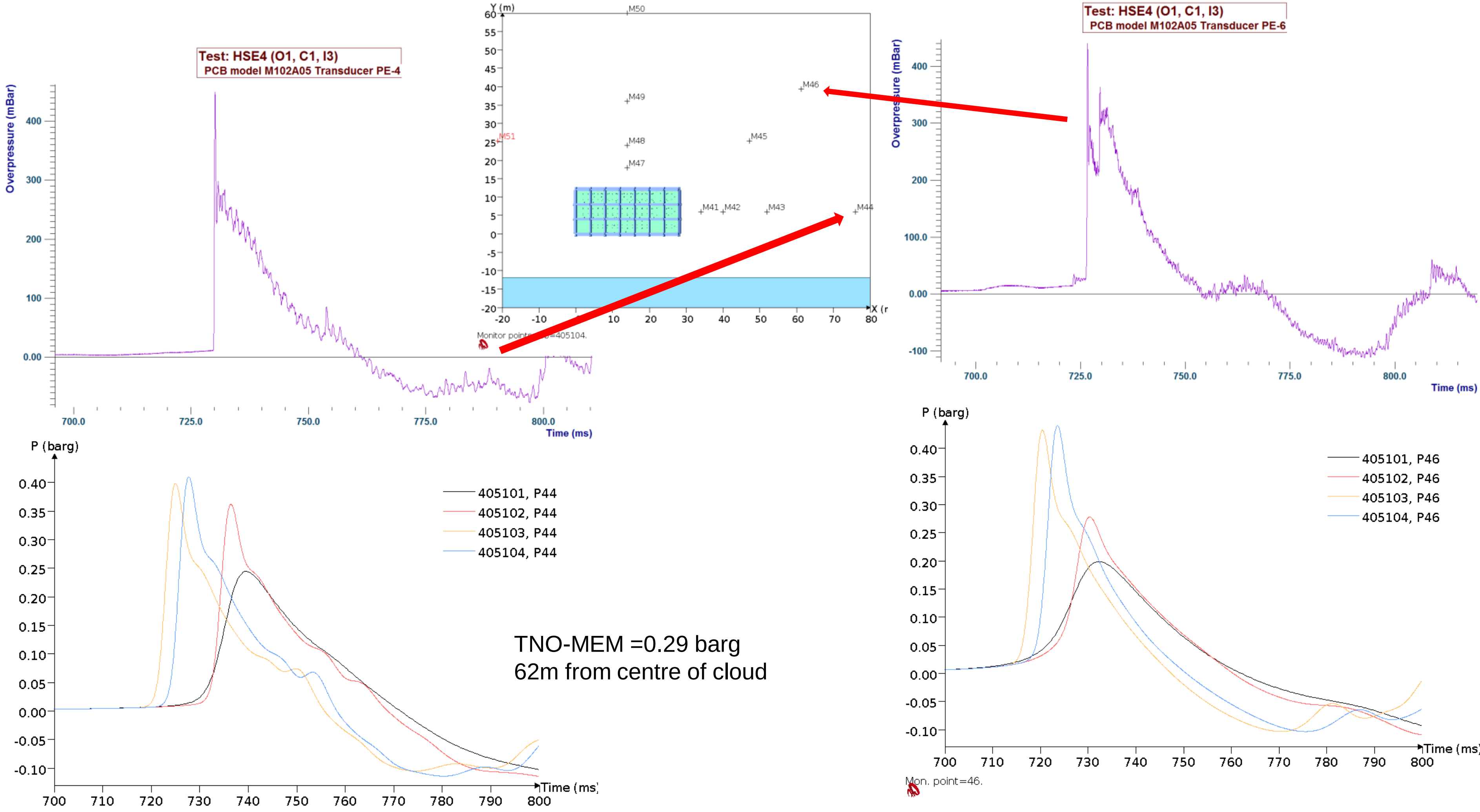
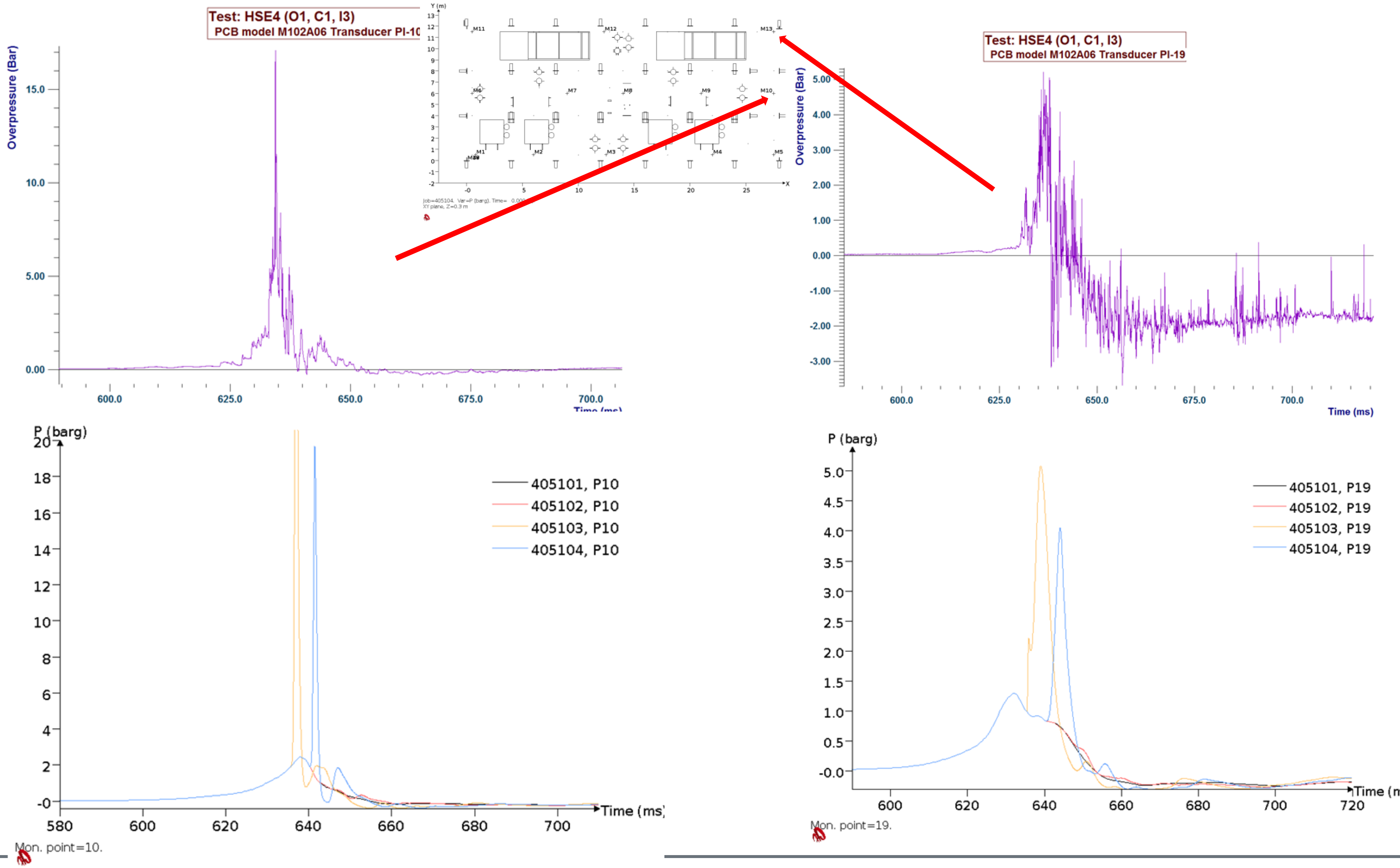


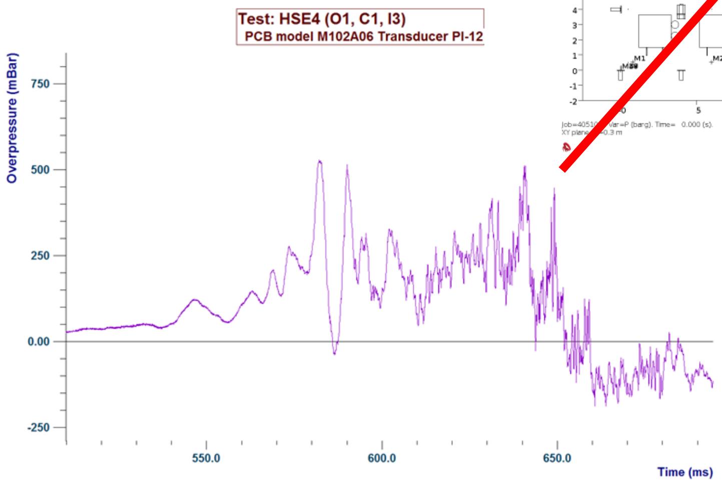
Notice:

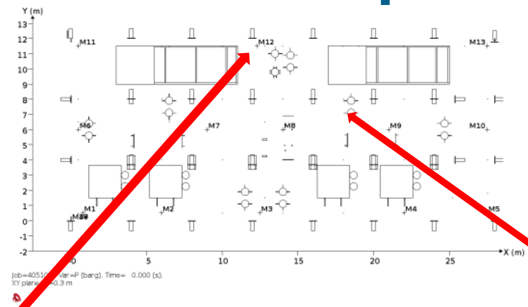
1. **While DDT pressures are very similar at 0 and 45 degree angles, deflagration pressures are 30% stronger straight out**
2. **At 24m distance DDT pressures were 3-4 times higher than deflagration pressures, at 48m they are almost same**
3. **Illustrating different nature of DDT and deflagrations? DDT more energetic (outside rig), but sends energy in all directions!**

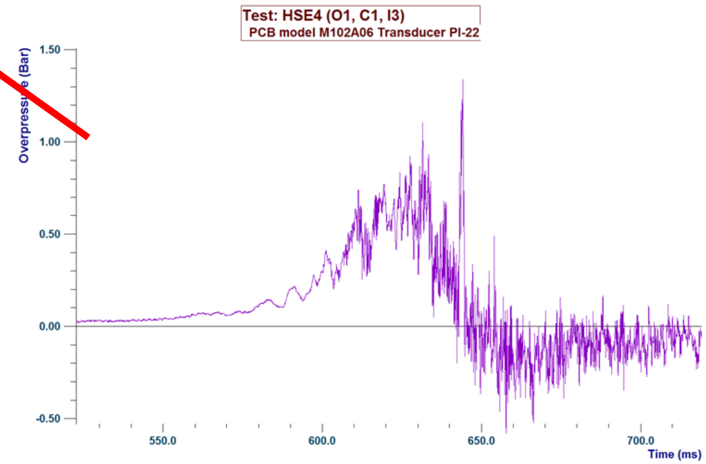
Pressures where flames exit module

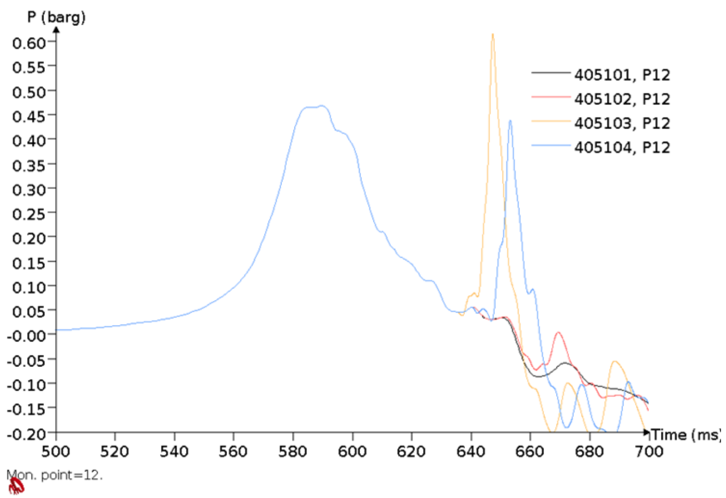


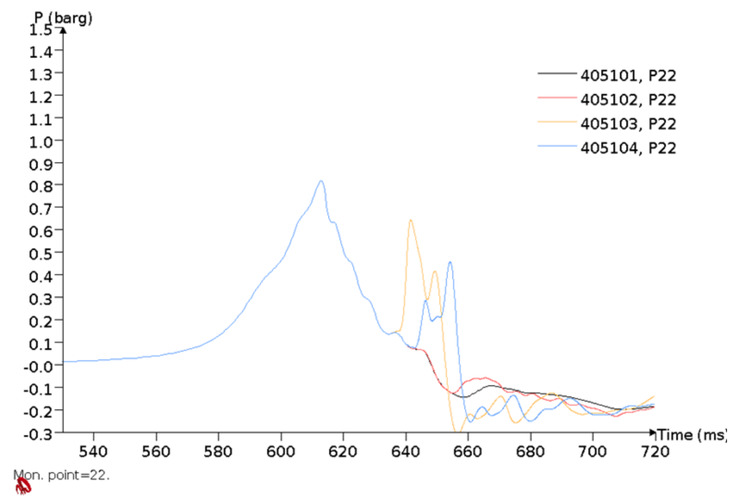
Pressure dynamics in central part of module











Observations & Implications I

Simulations substantiate the case that a DDT took place for HSE Test 4 (and later tests)

⇒ **Strong natural gas explosions may see DDT**

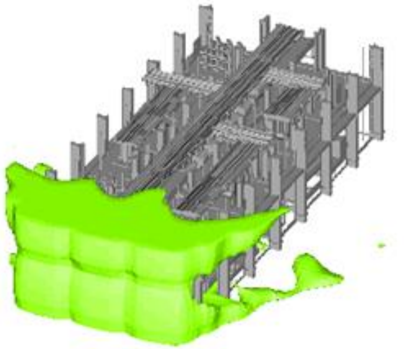
Buncefield/Jaipur/Sunrise & Buncefield tests++ conclude same for propane/petrol vapour

Bad news:

Compared to traditional studies blast consequences away from explosion get much worse

Detonation in **small pocket of gas** gives dramatic changes

2-4 times higher pressures 1-3 “cloud diameters” away



What if pocket is much larger

or dense gas cloud continues outside module?

Observations & Implications II

Good news: Risk and potential consequences for this can be evaluated

- Predict propensity for DDT (DPDX & λ criteria)
- Optimize layout to minimize DPDX
- With new approach/guidelines far-field blast (with/without DDT) can be well predicted

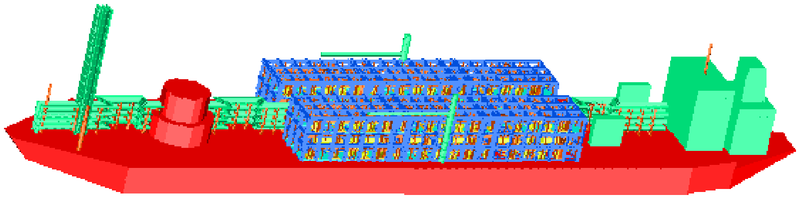
Not so difficult to “tweak” FLACS to get something which “looks” like DDT, somewhat more challenging to get far field pressures and flame speeds right

Should be of significant interest for FPSOs, FLNGs and onshore plants

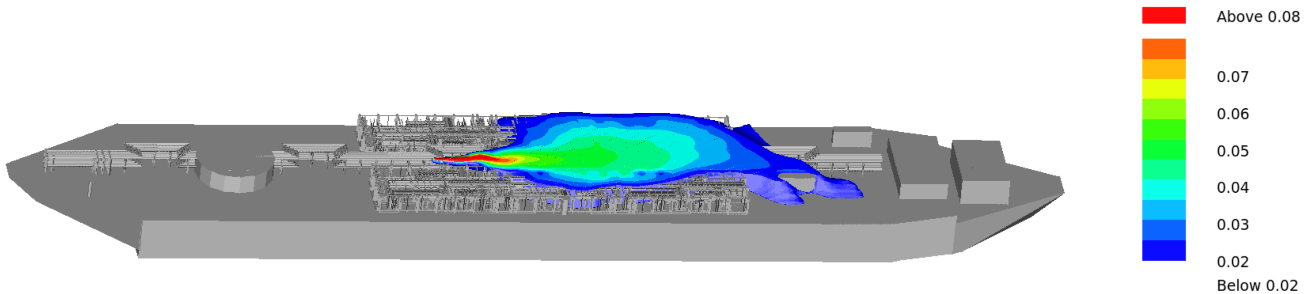
Example case

“FPSO”:

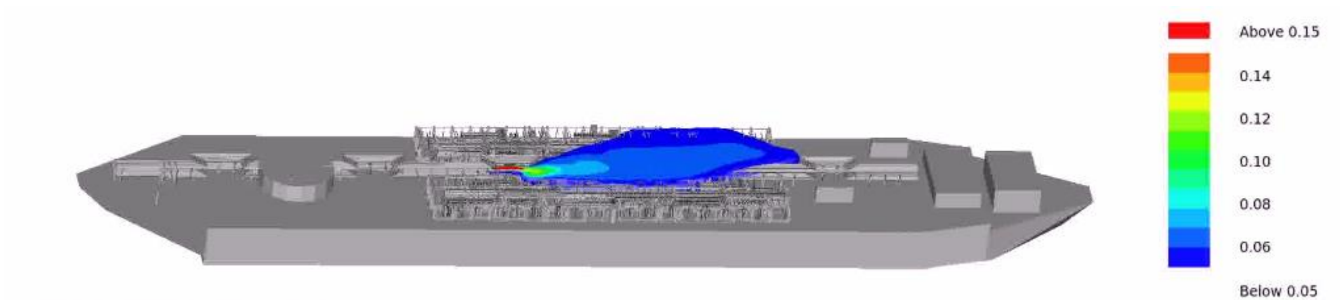
Could large gas releases give DDT potential?



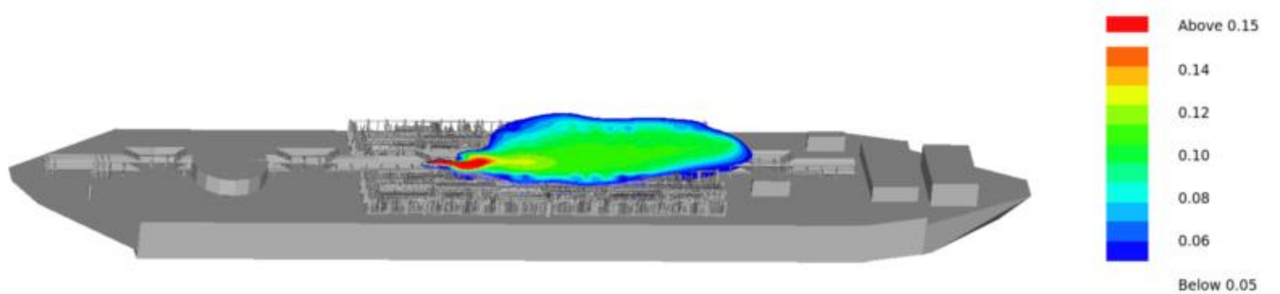
- 50 kg/s propane



- 50 kg/s methane



- 100 kg/s methane



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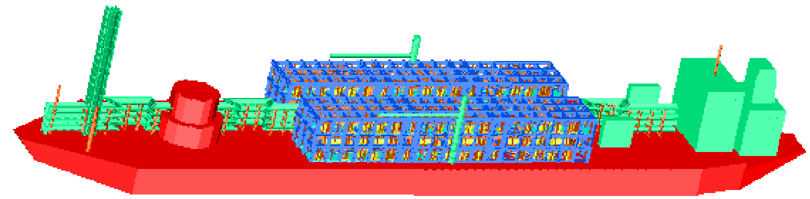
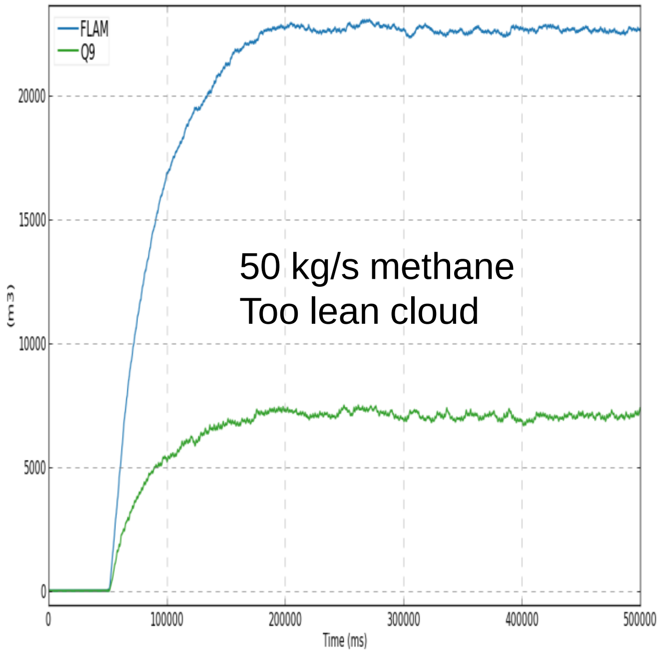
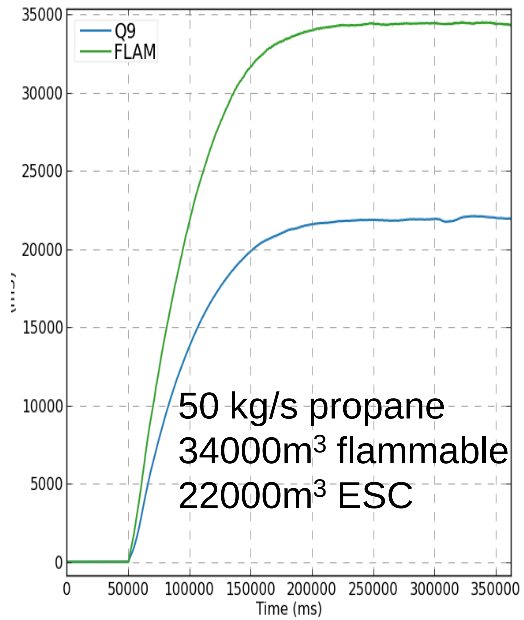
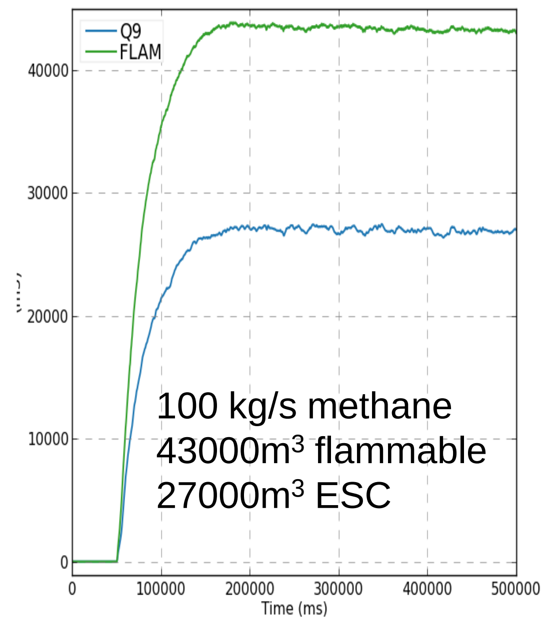




Run: 710001
Var: FLAM, Q9



Run: 700001
Var: FLAM, Q9

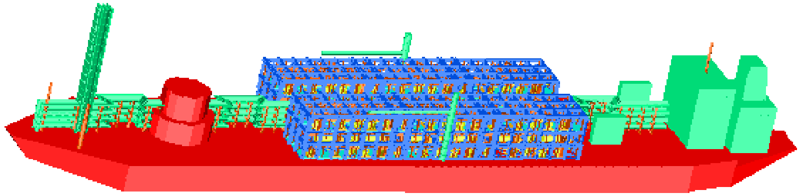


Run: 710003
Var: FLAM, Q9

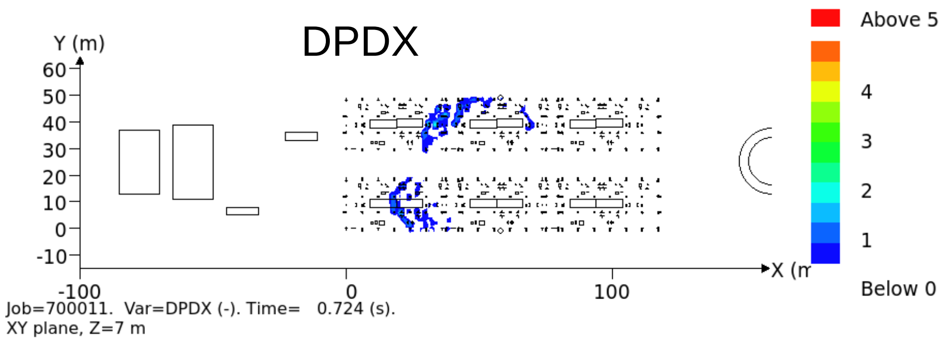
Example case

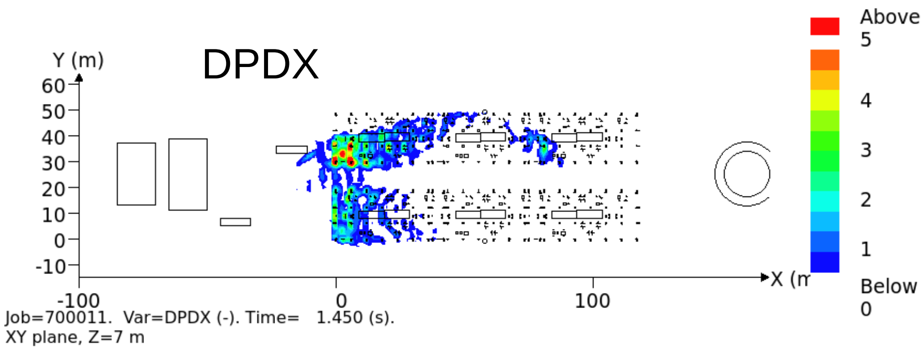
“FPSO”:

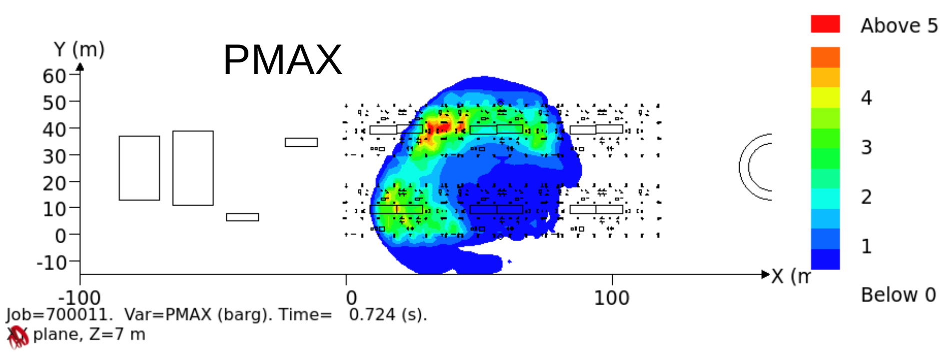
Could large gas releases give DDT potential?

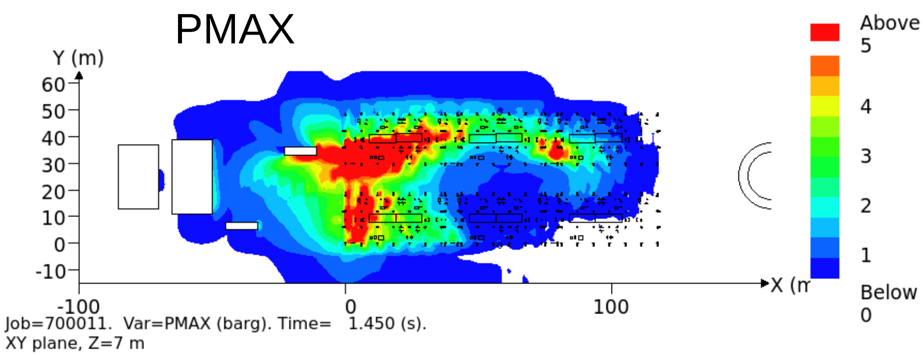


Propane cloud explosion









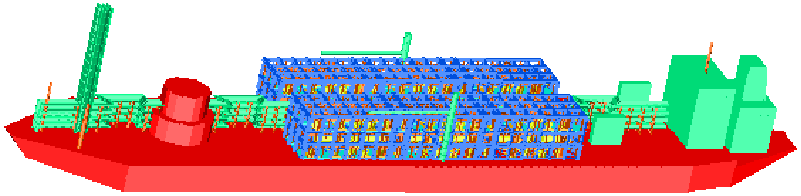
Likely time of DDT

End of deflagration simulation

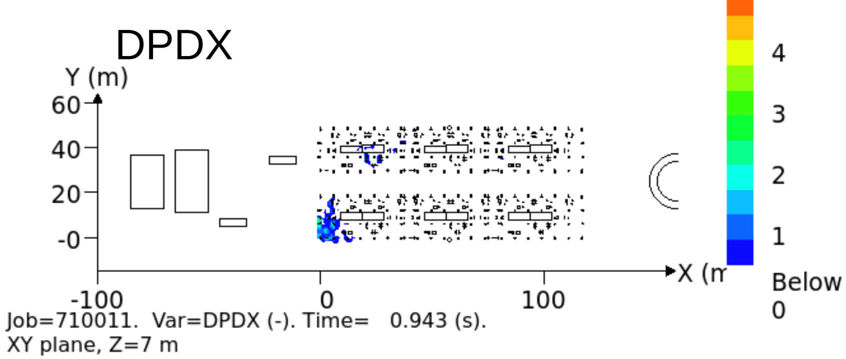
Example case

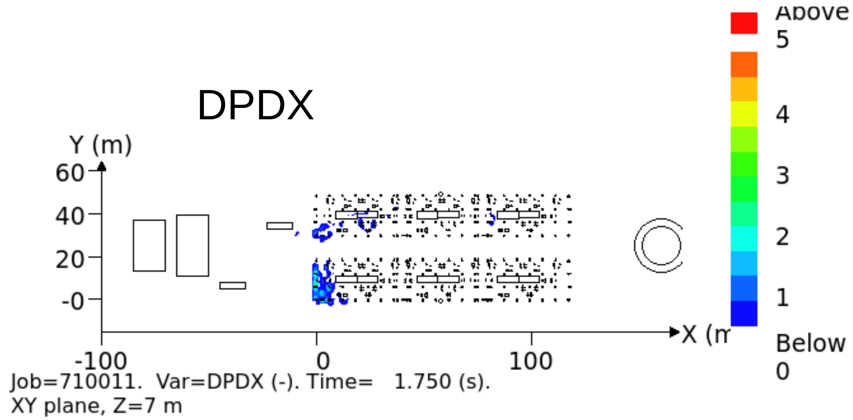
“FPSO”:

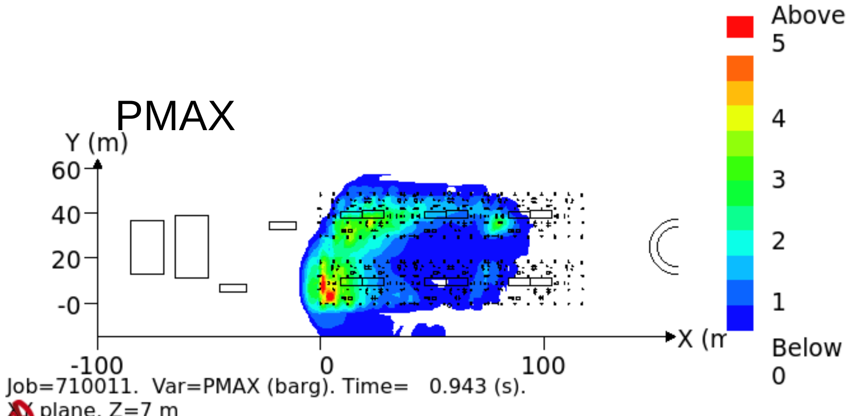
Could large gas releases give DDT potential?



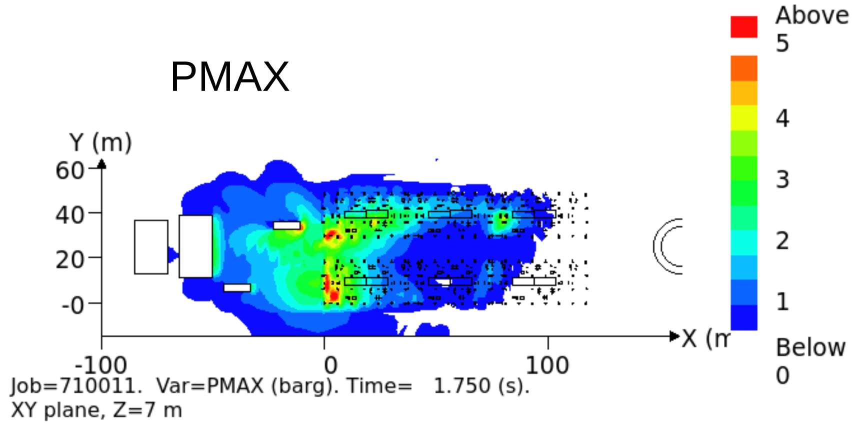
Methane cloud explosion







Likely time of DDT

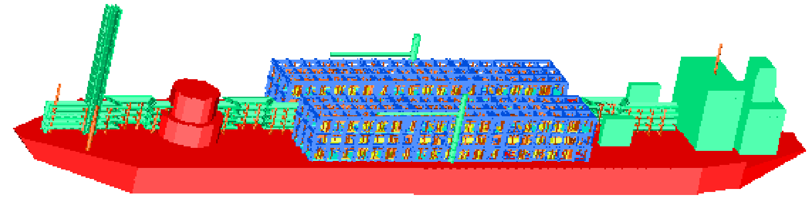


End of deflagration simulation

Example case

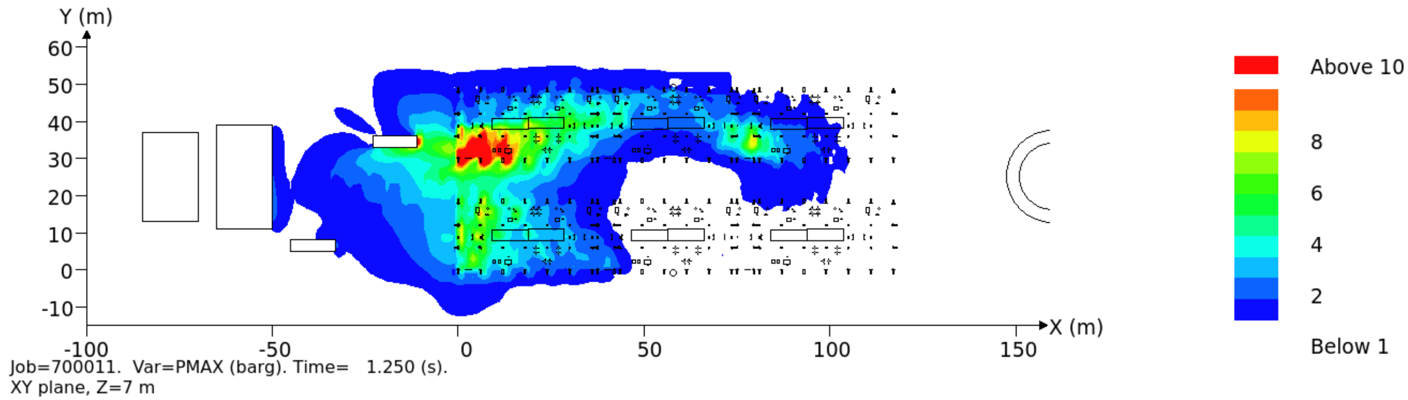
“FPSO”:

Could large gas releases give DDT potential?

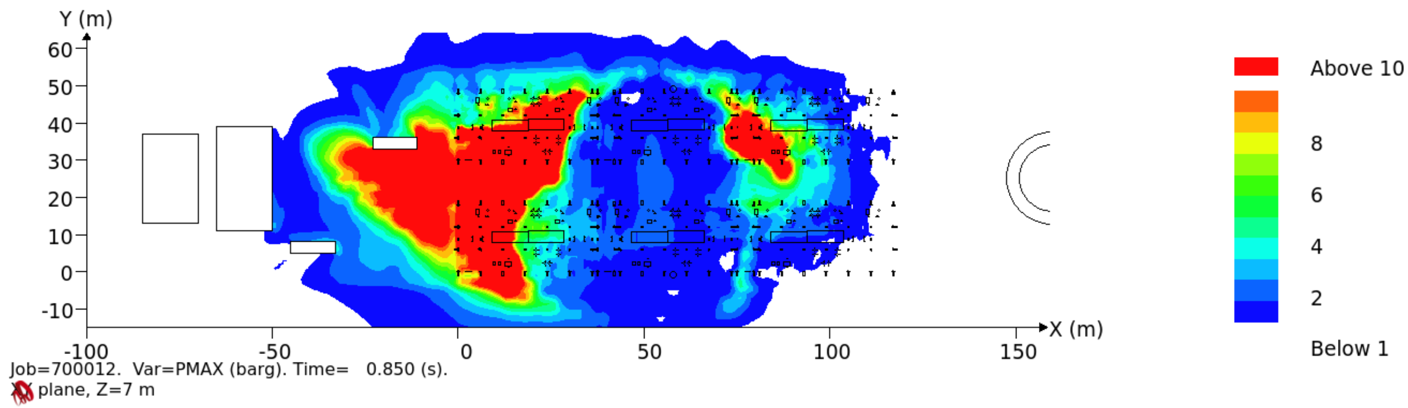


Propane cloud predicted maximum pressures (video)

Deflagration



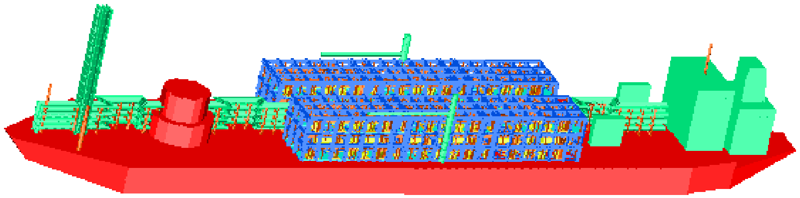
Assuming DDT



Example case

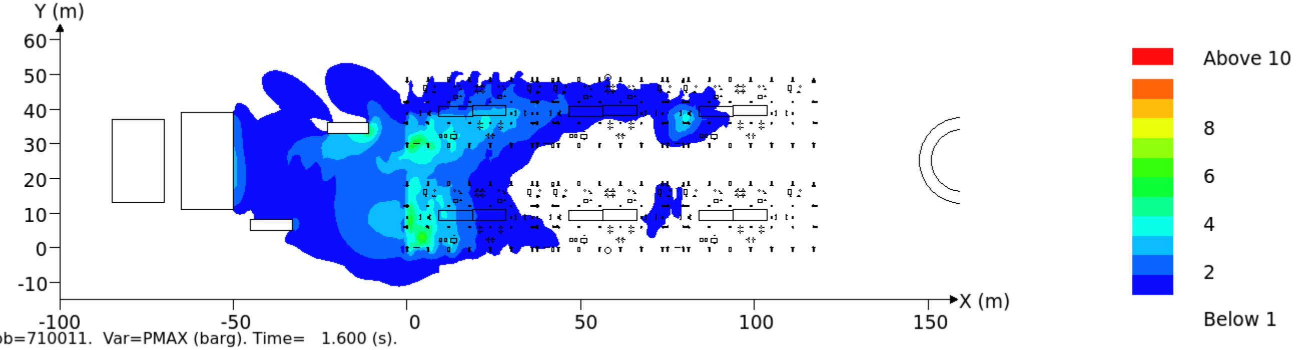
“FPSO”:

Could large gas releases give DDT potential?



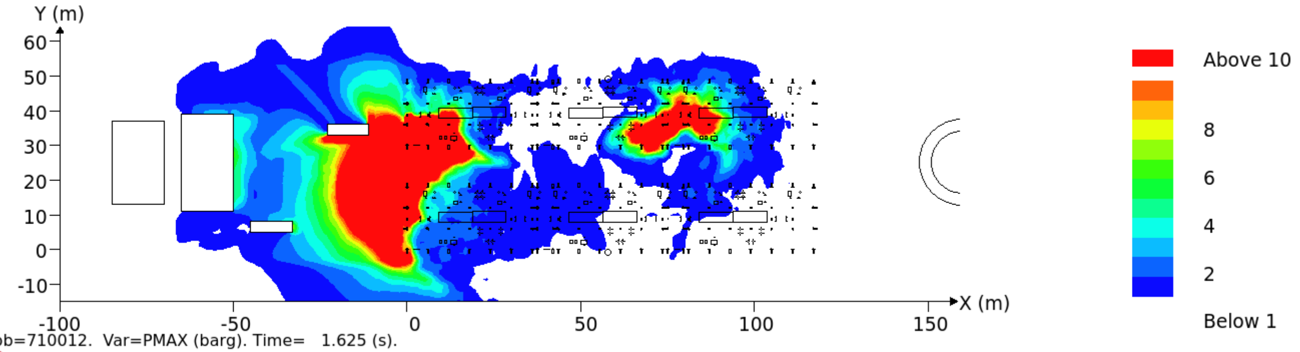
Methane cloud predicted maximum pressures (video)

Deflagration



Job=710011. Var=PMAX (barg). Time= 1.600 (s).
XY plane, Z=7 m

Assuming DDT

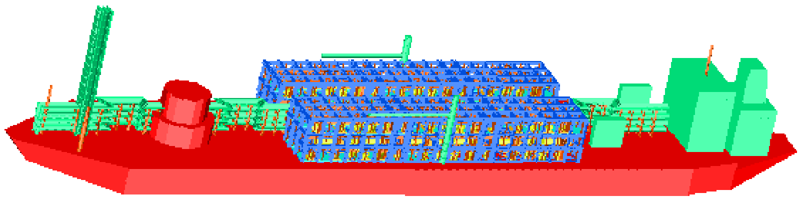


Job=710012. Var=PMAX (barg). Time= 1.625 (s).
XY plane, Z=7 m

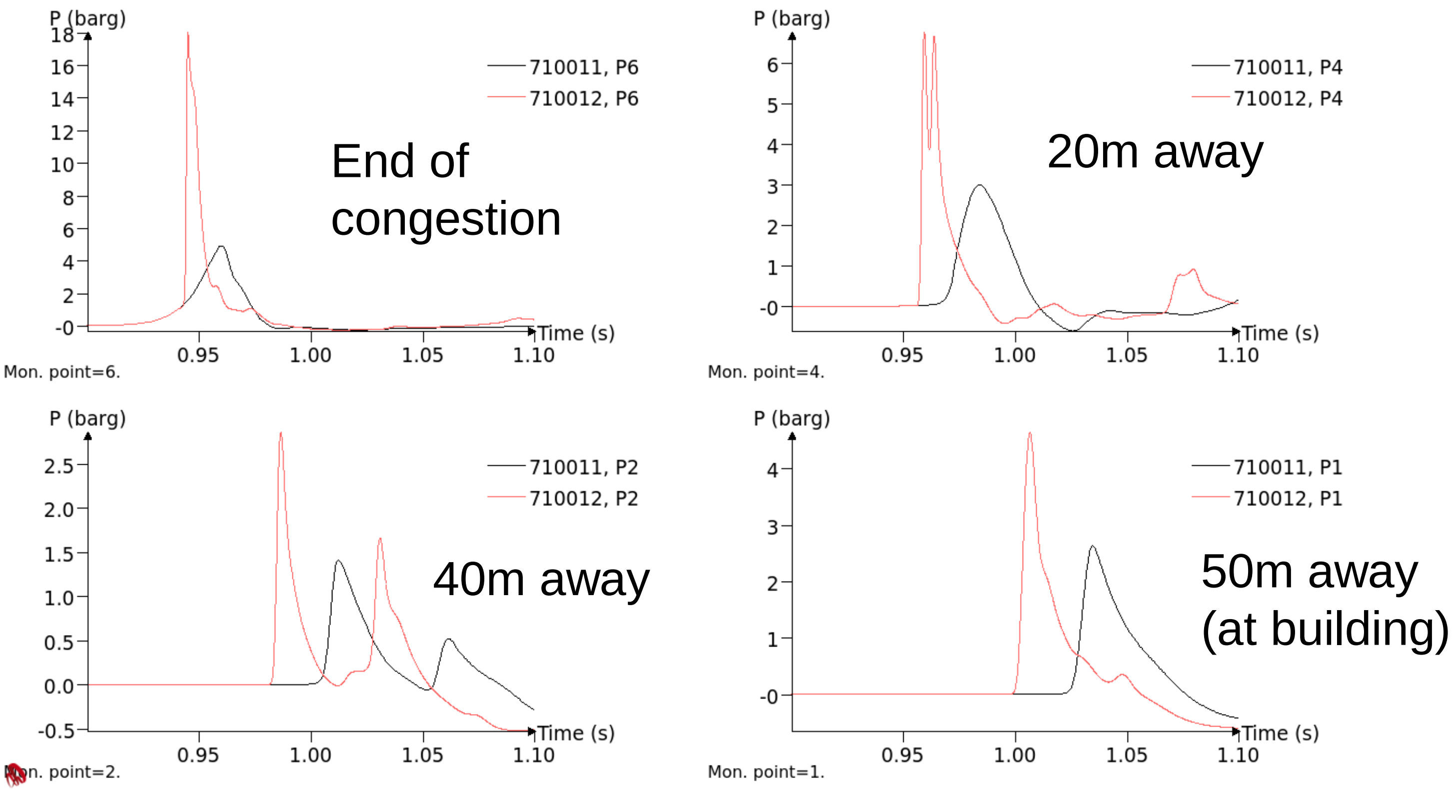
Example case

“FPSO”:

Could large gas releases give DDT potential?



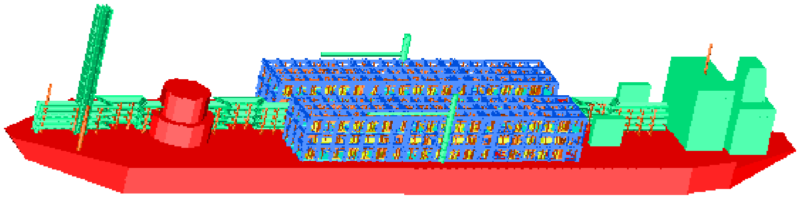
Methane pressure sensors (red curve assuming DDT, black curve deflagration)



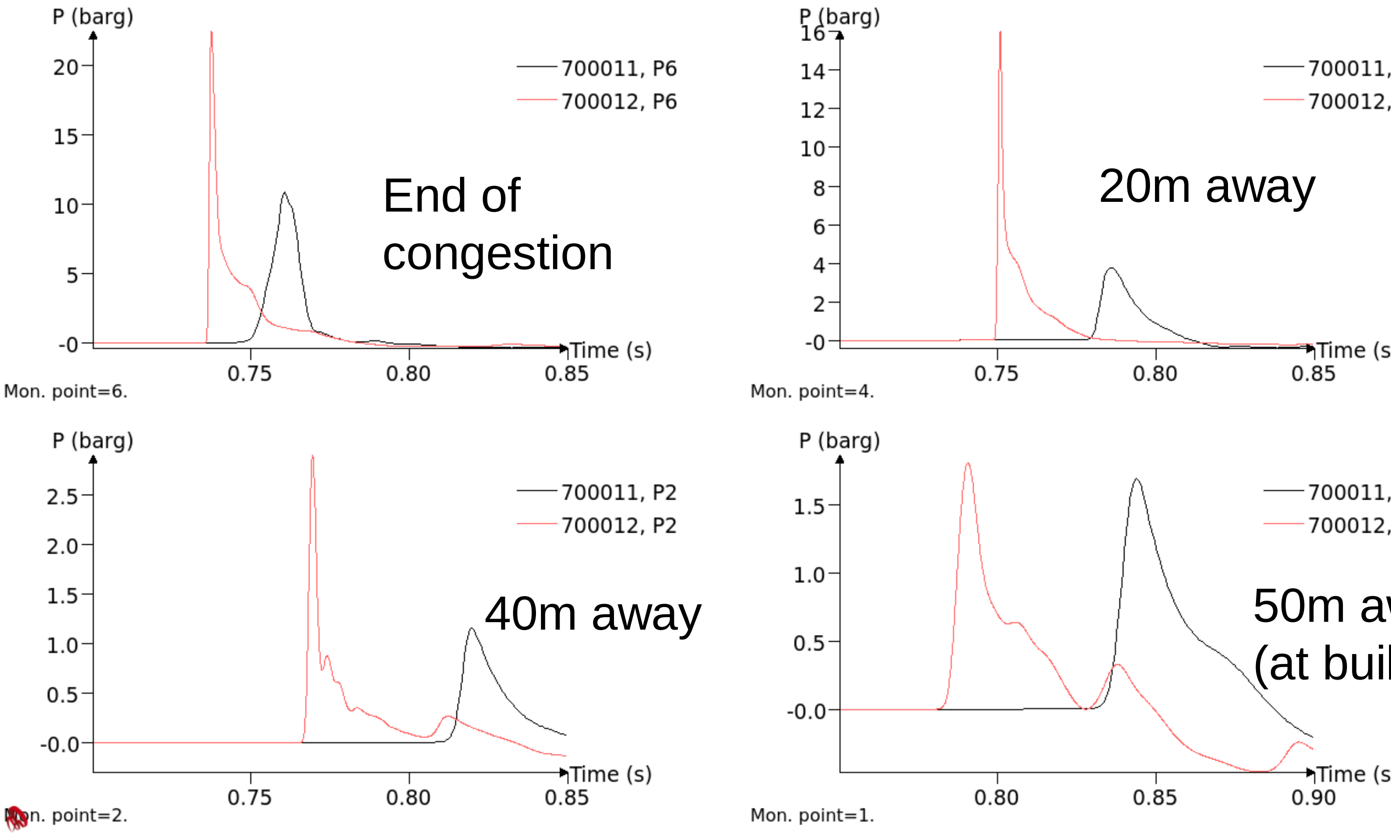
Example case

"FPSO":

Could large gas releases give DDT potential?



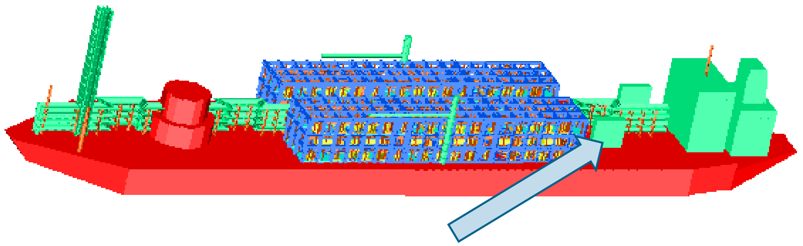
Propane pressure sensors(red curve assuming DDT, black curve deflagration)



Example case

“FPSO”:

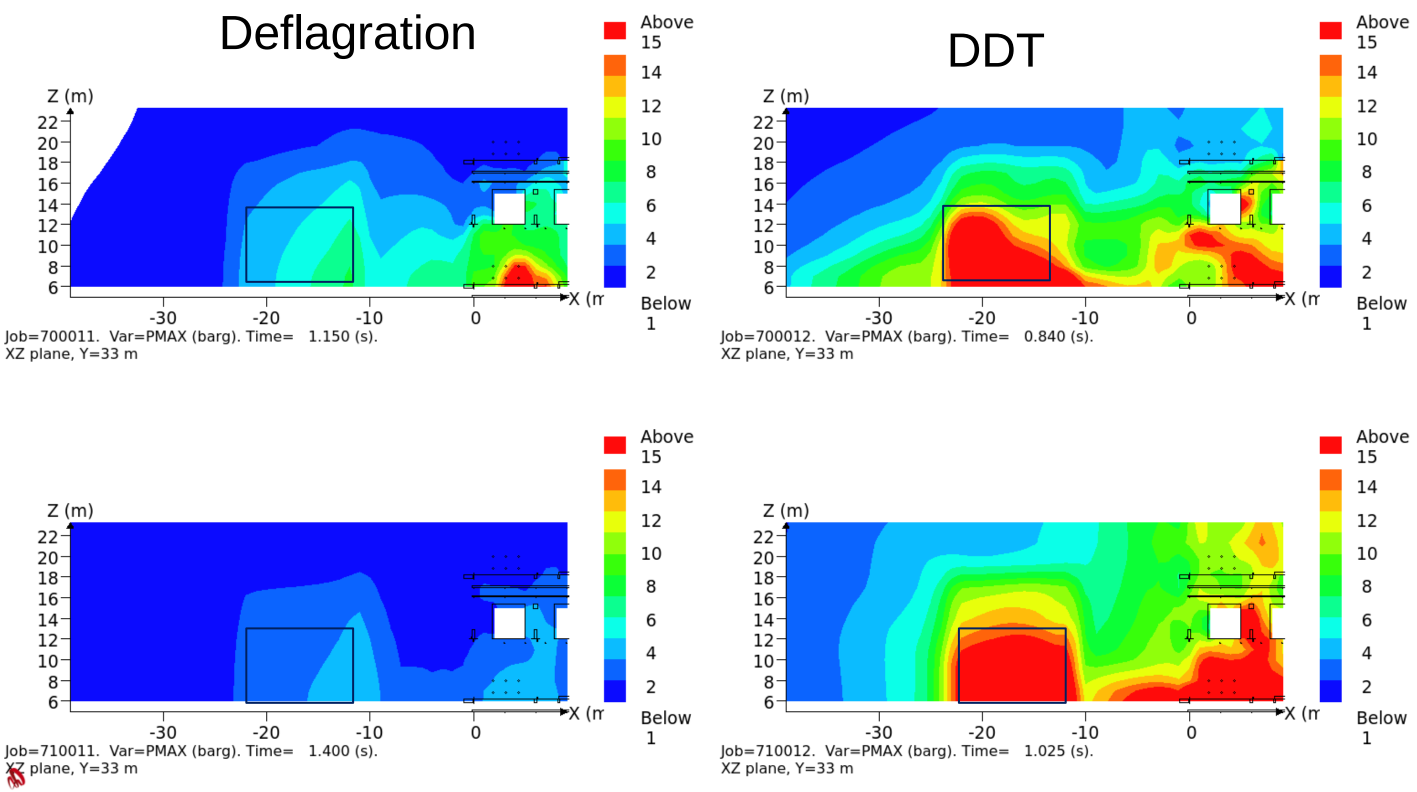
Could large gas releases give DDT potential?



«side-on» loads on building 10-20m outside congestion

Propane

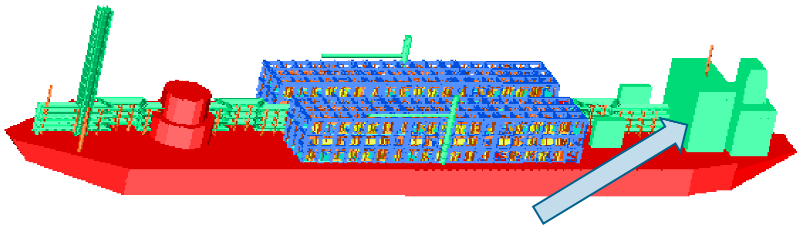
Methane



Example case

“FPSO”:

Could large gas releases give DDT potential?

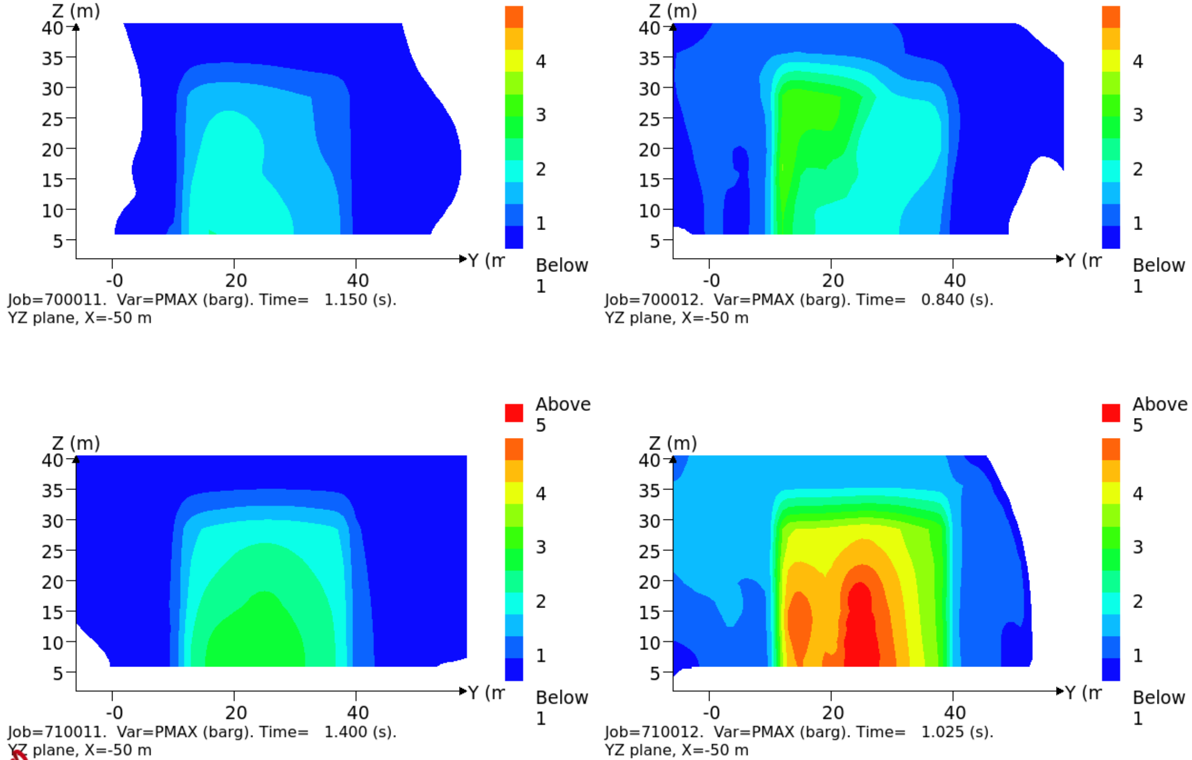


Reflected loads on building 50m outside congestion

Propane

Methane

Deflagration | DDT



Conclusions

- Onshore industry/authorities should exploit the benefits of CFD, not rule out the use of CFD
- DDT is a “credible event”, and can make far-field explosion loads MUCH more severe, even for natural gas in offshore situations
- There is a need to optimise facility layout/congestion to minimize risk for DDT and limit explosion pressures
- GL has demonstrated ability to predict DDT and its consequences

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