



FLACS

CFD Model developed by GexCon

For more information:

flacs@gexcon.com

www.gexcon.com

GexCon today

” GexCon aims to be the most recognized company within the field of explosion-, gas dispersion- and fire safety”



■ Leading provider of:

- Software for simulation of explosions, gas dispersion and fires
 - Consultancy service for explosion-, gas dispersion- and fire- safety
 - Explosion testing of equipment and substances (large and small scale)
 - R&D within explosion, dispersion and wind
- 400 man-years of explosion experience, through R&D-projects, FLACS based consulting, accident investigation and laboratory testing

Gas safety research 1970-2005

1970s How it started

- Norway starts exploring oil and gas
- Flixborough accident
- Need to learn more about mechanisms

1980s Gas Safety Programs at GexCon

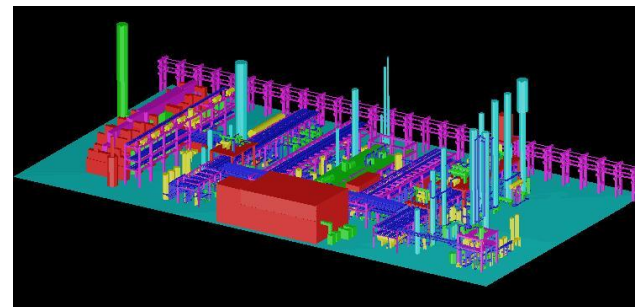
- 10 mill USD 1980-86, extensive testing and R&D
- **FLACS** Software development, first version 1986
- BP, ExxonMobil, Total, GDF, StatoilHydro used FLACS inhouse

1990s Gas Safety Programs at GexCon

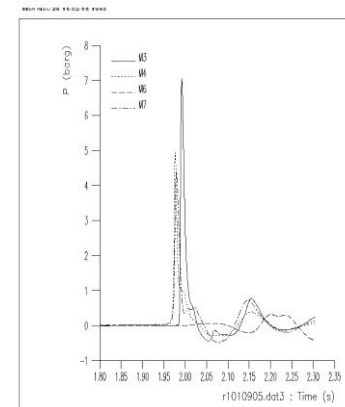
- Continuing test programs and FLACS model development
- **FLACS-96** made commercially available
- Focus on risk assessment, dispersion, CAD-import

2000s Various Activities

- Hydrogen, Dust Explosions, Fire
- Aerosols, Flashing, LNG pool-spread
- Visualization, Atmospheric dispersion



Onshore plant geometry model FLACS-89



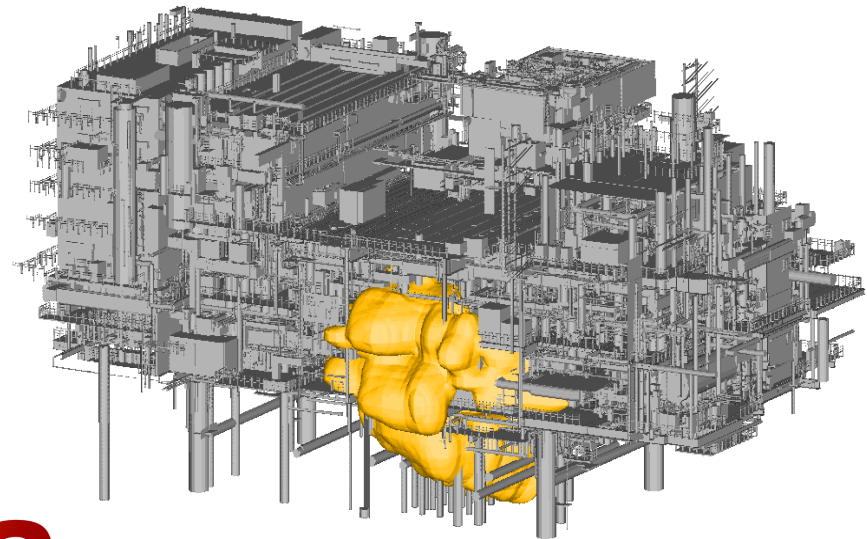
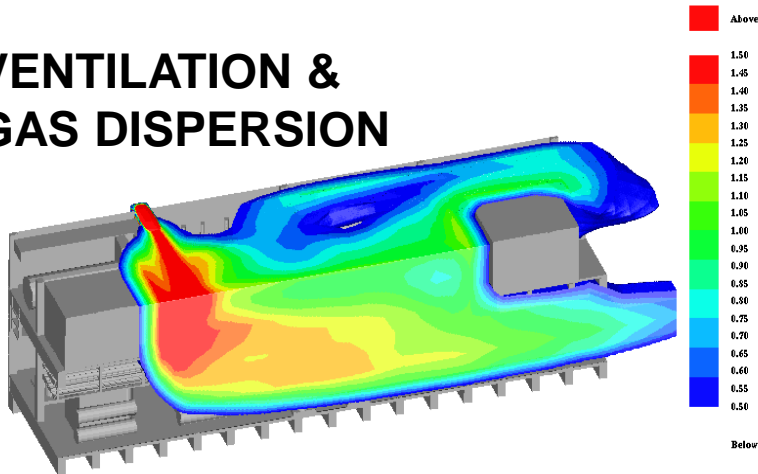
Pressure curves FLACS-89

FLACS Today

Status:

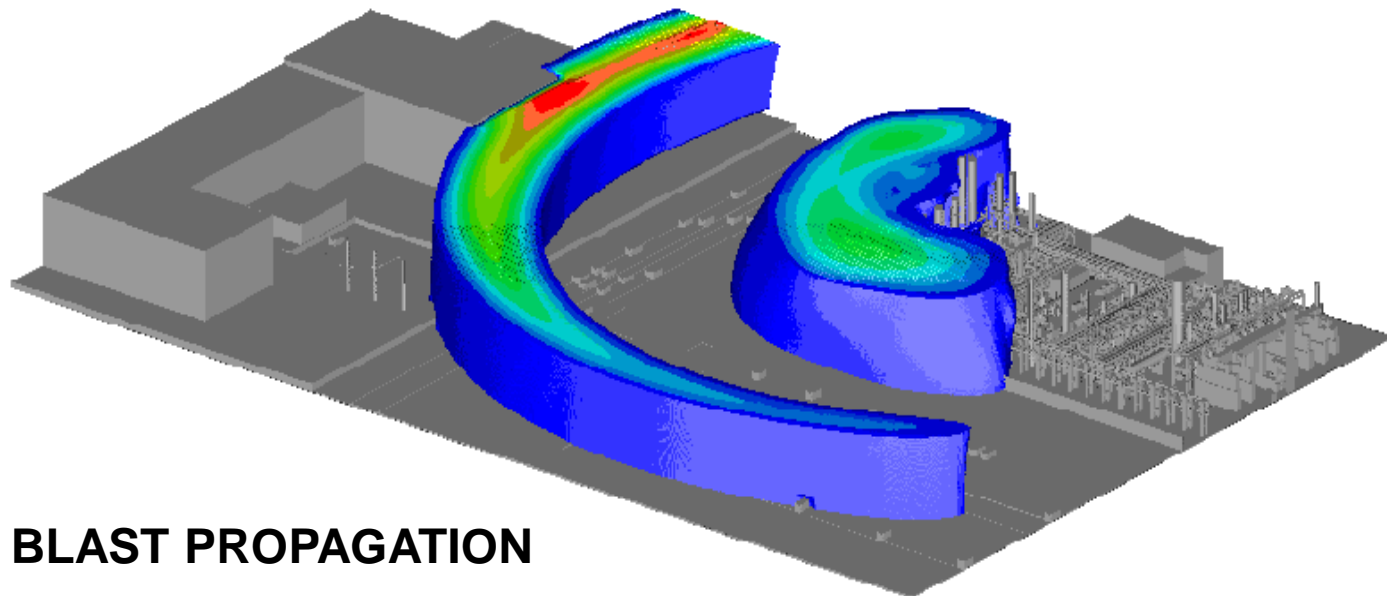
- World #1 gas explosion CFD (industry standard)
- World #1 in hydrogen safety
- Partly leading for dispersion in process plants
- DESC world #1 dust explosion CFD-tool
- Fire model (CFD) being developed

VENTILATION & GAS DISPERSION



 **FLACS**

GAS EXPLOSION



BLAST PROPAGATION

 **FLACS**

Clients

Geographically: All over the world

FLACS installations:

- ❑ Asia (Taiwan, Malaysia, Korea, Japan, Saudi-Arabia, China, Qatar),
- ❑ Europe (Norway, Belgium, UK, France, Switzerland, Germany, Italy, Spain, ...)
- ❑ America (USA, Brazil, Canada, Colombia),
- ❑ Australia
- ❑ Almost 80 installations in about 20 countries

Clients:

- ❑ Gas- and oil companies
- ❑ Chemical industry
- ❑ Engineering companies
- ❑ Consultants
- ❑ Nuclear industry
- ❑ Hydropower
- ❑ Authoritative bodies
- ❑ Research institutions
- ❑ Safety equipment
- ❑ Universities



Clients



What is CFD?

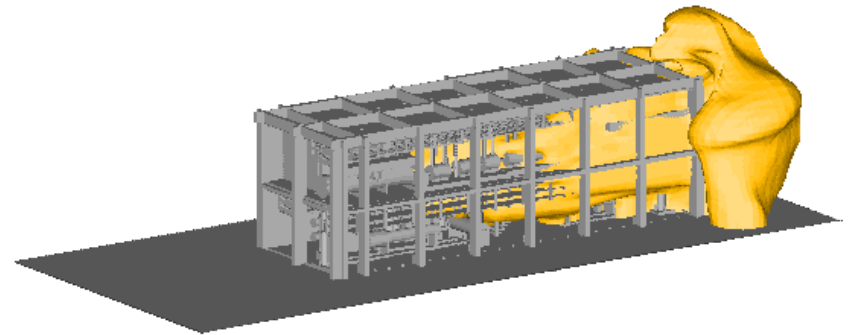
CFD = Computational Fluid Dynamics

- ❑ Define a simulation domain (part of the real world)
 - ❑ The domain is divided into boxes/volumes
 - ❑ Define initial conditions and boundary conditions
 - ❑ Solve conservation equations (Navier-Stokes + +)
- ⇒ Predict what will happen in the real world



Test from Advantica large scale test site

Test from GexCon test site simulated



Why use CFD?

For consequence modeling **scenario** and **geometry** are important:

Dispersion modeling:

- Buildings, vegetation or topography usually important

Explosion modeling

- Geometry very important (Congestion & confinement)

Simpler alternatives to CFD generally ignore geometry!

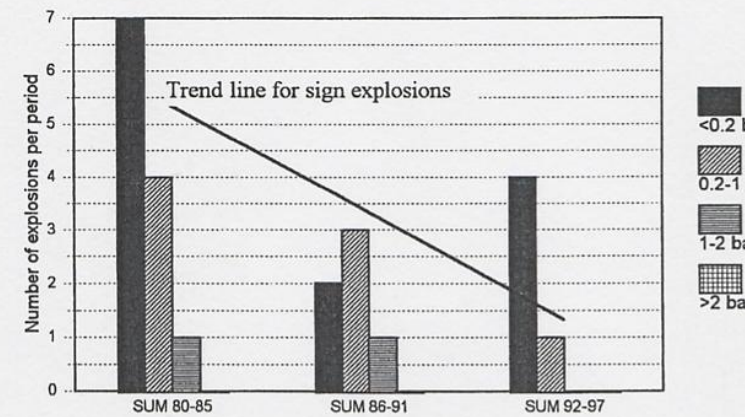
Same volume blockage, 15x15 thin pipes give > 100 times higher pressure than 3x3 larger



FLACS – Benefits

- Competent use of FLACS will reduce risk
- Cost effective decisions on safety issues (efficient to produce valid results)
- Well accepted by industry and authorities
- Access to competence and experience of GexCon through support and cooperation

The use of FLACS can explain past accidents
and reduce consequences of future accidents

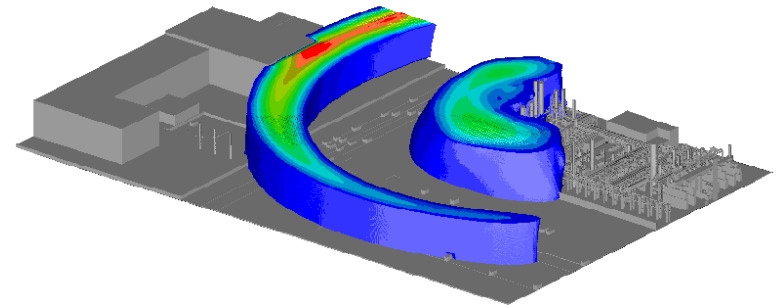
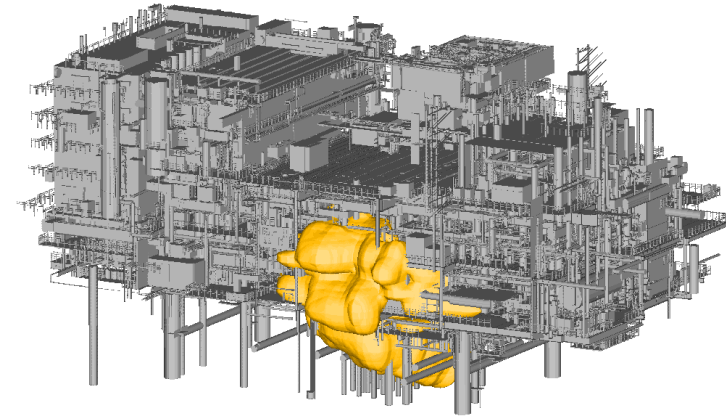


Number of significant explosions
in North-Sea platform is reduced

Wide applicability

Ventilation, gas dispersion and explosion onshore/offshore

- natural ventilation, HVAC, fans
- dispersion, low and high momentum releases
- practically any type of geometry
- variable gas cloud size (defined / from dispersion)
- variation of ignition location
- hydrocarbon gases + H_2S + hydrogen+CO
- any mixture and concentration of the above gases
- pressure relief panels
- effect of water deluge, inert gases, CO_2 and N_2 , O_2
- prediction of blast strength in far field
- initial condition: temperature / pressure / turbulence
- liquid particles / oil mist
- Fire functionality under development

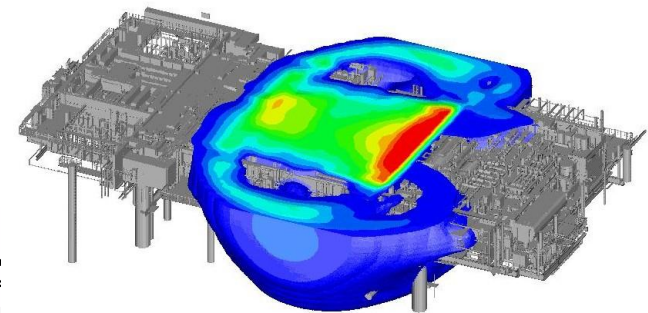
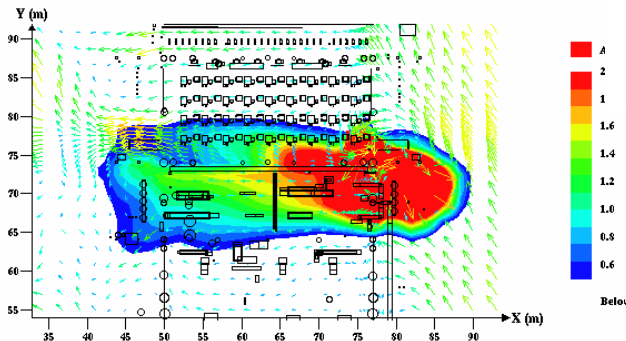
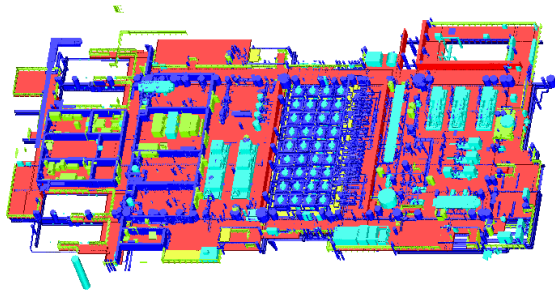


Blast wave propagation
effect of buildings

FLACS – application areas (1)

Consequence studies offshore/onshore on e.g.

- ❑ Efficient geometry import from dgn-files (and some other formats)
- ❑ Ventilation (including helideck studies, natural ventilation, HVAC)
- ❑ Release and Dispersion (gas, pool-spread and evaporation, flashing releases)
- ❑ Explosion (main feature, wide functionality)
- ❑ Fire functionality is under development
- ❑ Far field pressure waves
- ❑ Used for risk assessments, mitigation, accident/incident investigation and more



FLACS – application areas (2)

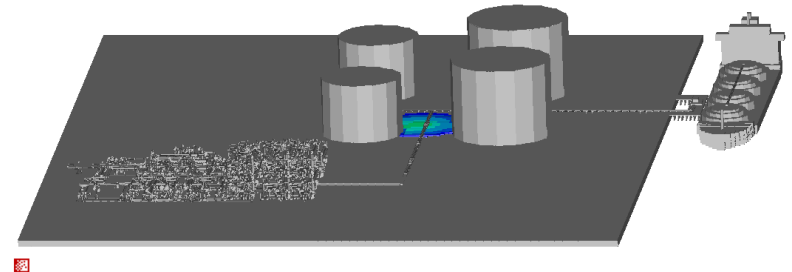
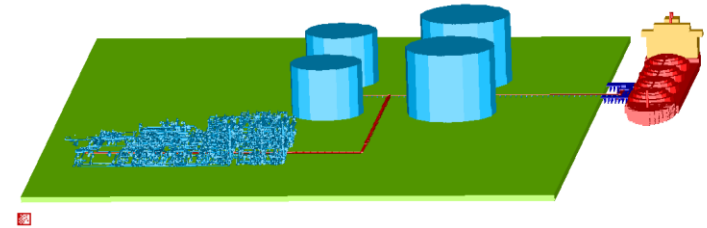
Similar consequence studies for other industries, e.g.

- Hydrogen safety, new energy or nuclear plant
- Coal mines, transformer explosions in substations
- Transportation, pipelines, LNG-carriers (storage/leaks and exhaust-pipe explosions)



GexCon did safety study for
Gas fuelled ferries (natural gas)

In Norway there is also work with hydrogen ships



FLACS – application areas (3)

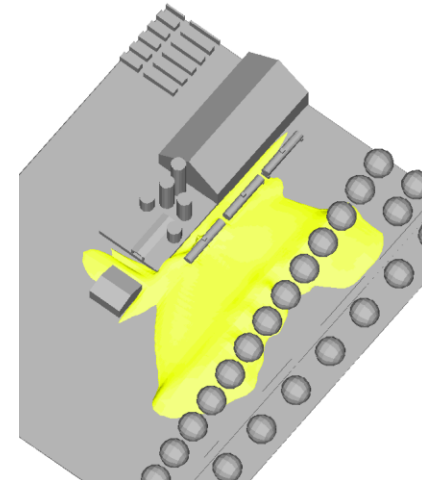
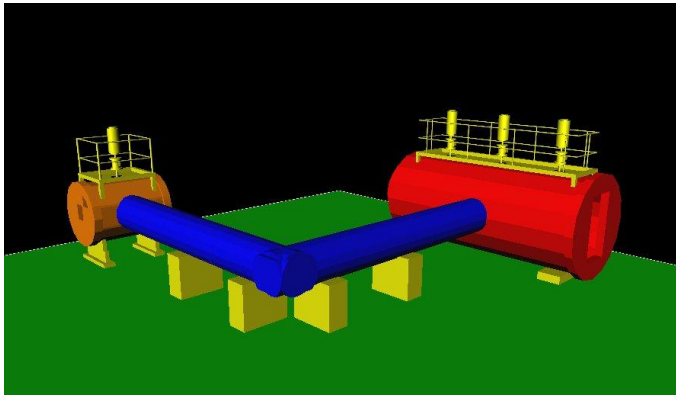
Dispersion of toxic gases

- Tracer gas in urban areas
- Chlorine releases from railcars
- H₂S from reservoirs, CO₂ injection issues



DESC tool (based on FLACS)

- Dust explosion modeling for process industry and more



FLACS – Advantages (1)

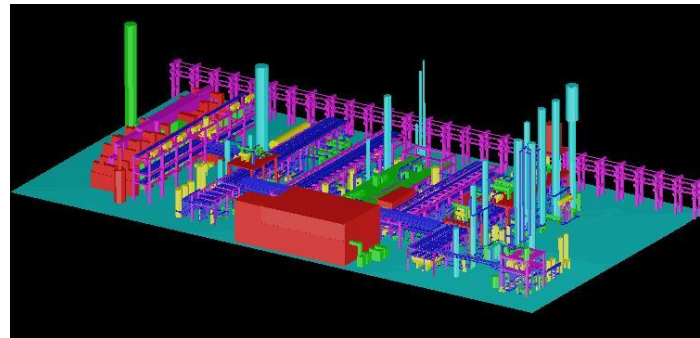
- Developed together with oil and gas industry with offshore safety in mind
- Developed by experts in physical understanding (with own test facilities)
- Continuing active development



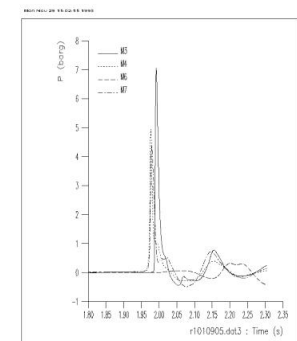
♣ M24/M25 (1985-86)



Phase 3B (1999)



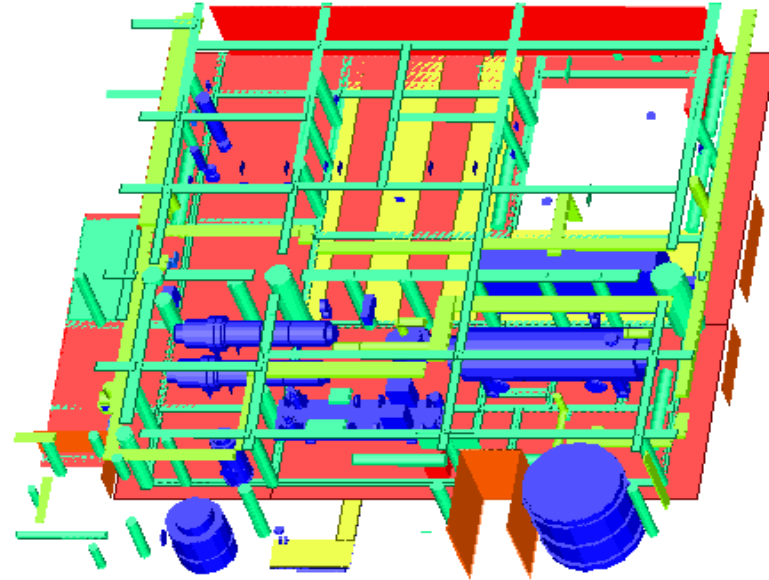
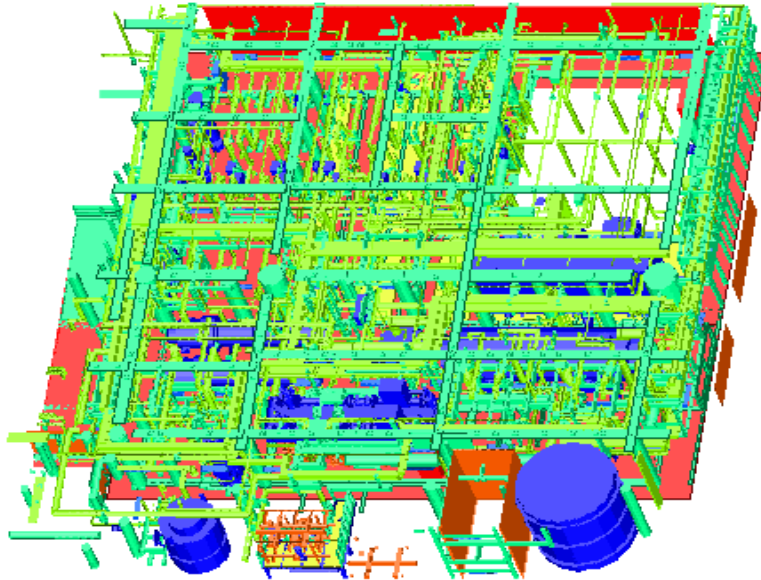
1990: 7 large oil & gas companies used
FLACS in-house to assess explosion risk



Geometry model must be accurate

A proper geometry representation is

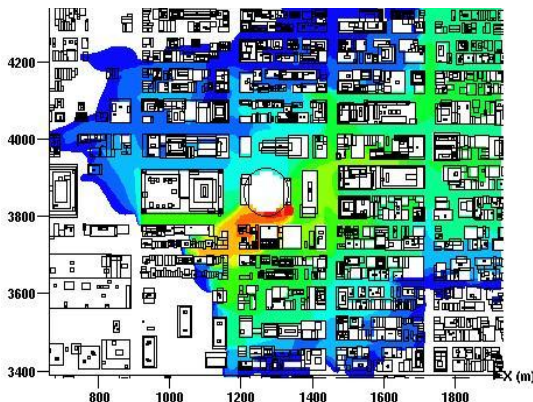
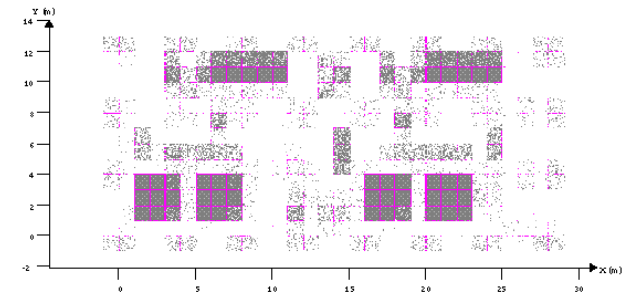
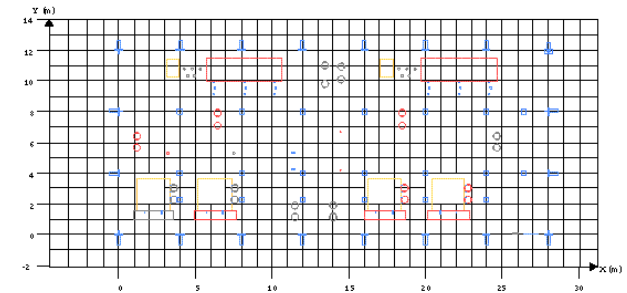
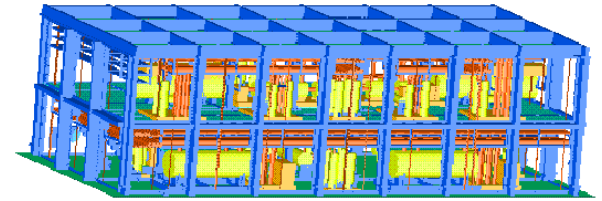
- Important for ventilation studies
- Very important for dispersion studies
- Essential for explosion studies



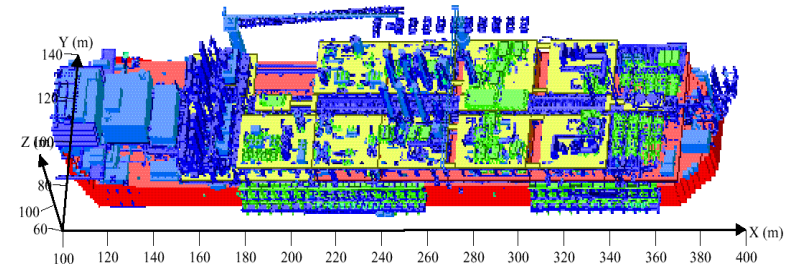
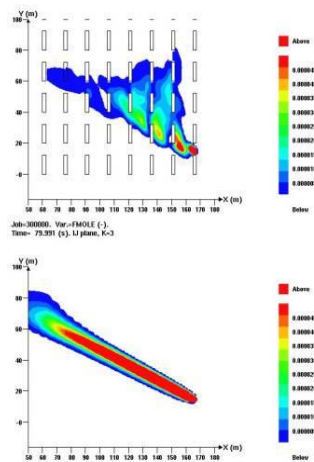
For most studies CAD model is imported, and anticipated congestion methods (ACM) are used

FLACS – Advantages(2)

- Geometry handling efficient (relative to other CFD-tools)
 - ⇒ porosity concept
 - ⇒ sub-grid modeling
- Same geometry dispersion & explosion (&fire)
 - ⇒ Very efficient concept
 - ⇒ FLACS interfaces can handle 100.000+ geometries
- CFD superior to simple tools which ignore geometry
 - ⇒ 15x15 small pipes => 100 times higher pressure
 - ⇒ Dispersion becomes unrealistic without geometry details



Job=620200. Var=FMOL (m3/m3) /log10/. Time=3600.087 (s).
XY plane, Z=15 m



FLACS – Advantages (3): Validation

FLACS validated against numerous tests

- Various ventilation studies (offshore platforms)
- Dispersion experiments (wind tunnel & field tests)
- Explosion experiments (wide range of scenarios)

BFETS Phase II : Test 12

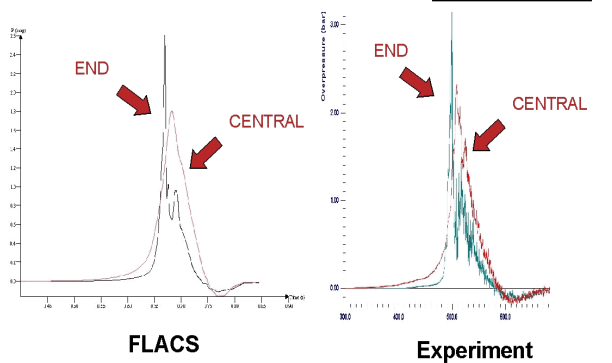
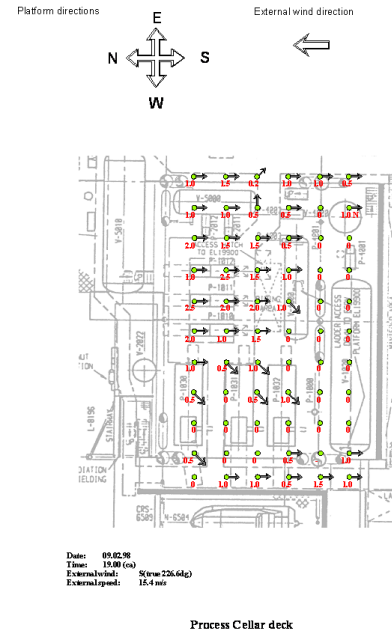
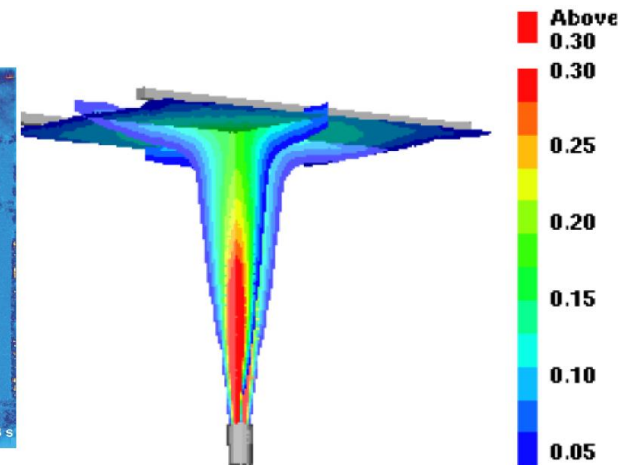
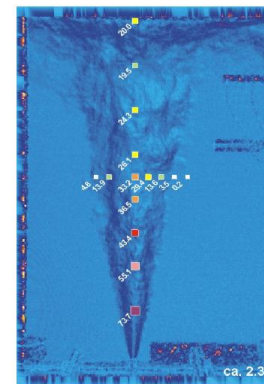


Photo shows GexCon wind measurements at Nelson Platform



Recent blind prediction activities

- H₂ dispersion INERIS 6C (18 HySafe partners)
- Shell H₂ explosions (fuel station + pipe arrays)
- FZK H₂ workshop ignited jets (HySafe)
- Dispersion scenarios at Manhattan (PNNL)
- Coal mine methane explosion tests (NIOSH)



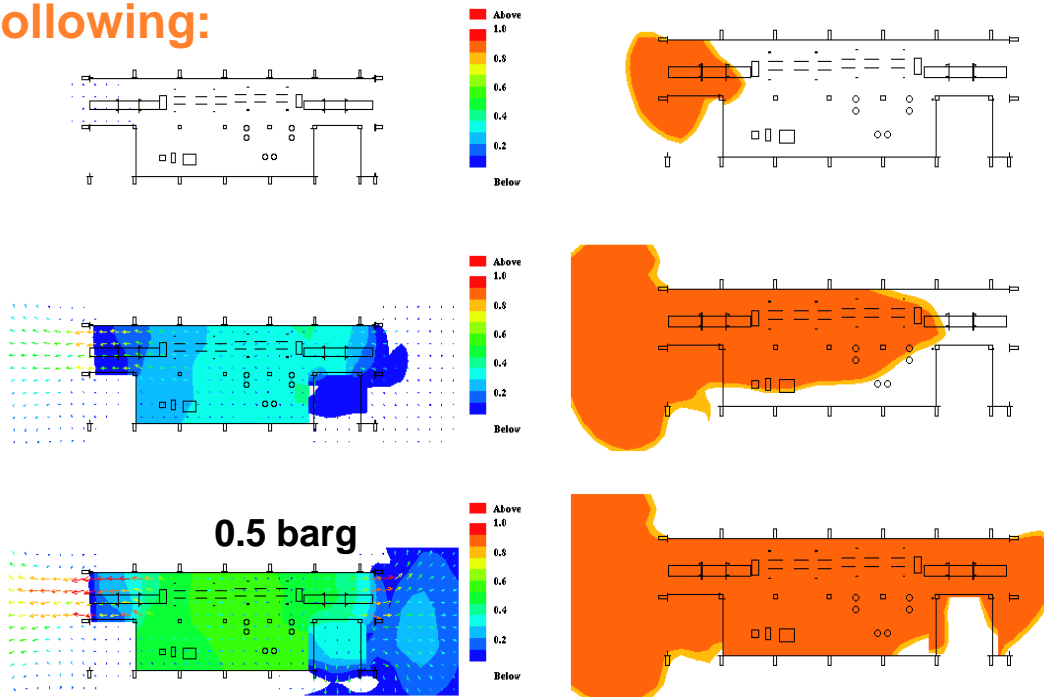
Why bother about validation?



FLACS sometimes used for "100 million Euro" decisions

- Important that validity is acceptable, high priority for FLACS
- 1980s & 90s; millions invested in validation tests

Consider an explosion at an installation, your consultant predicts the following:



Do you believe in this result?

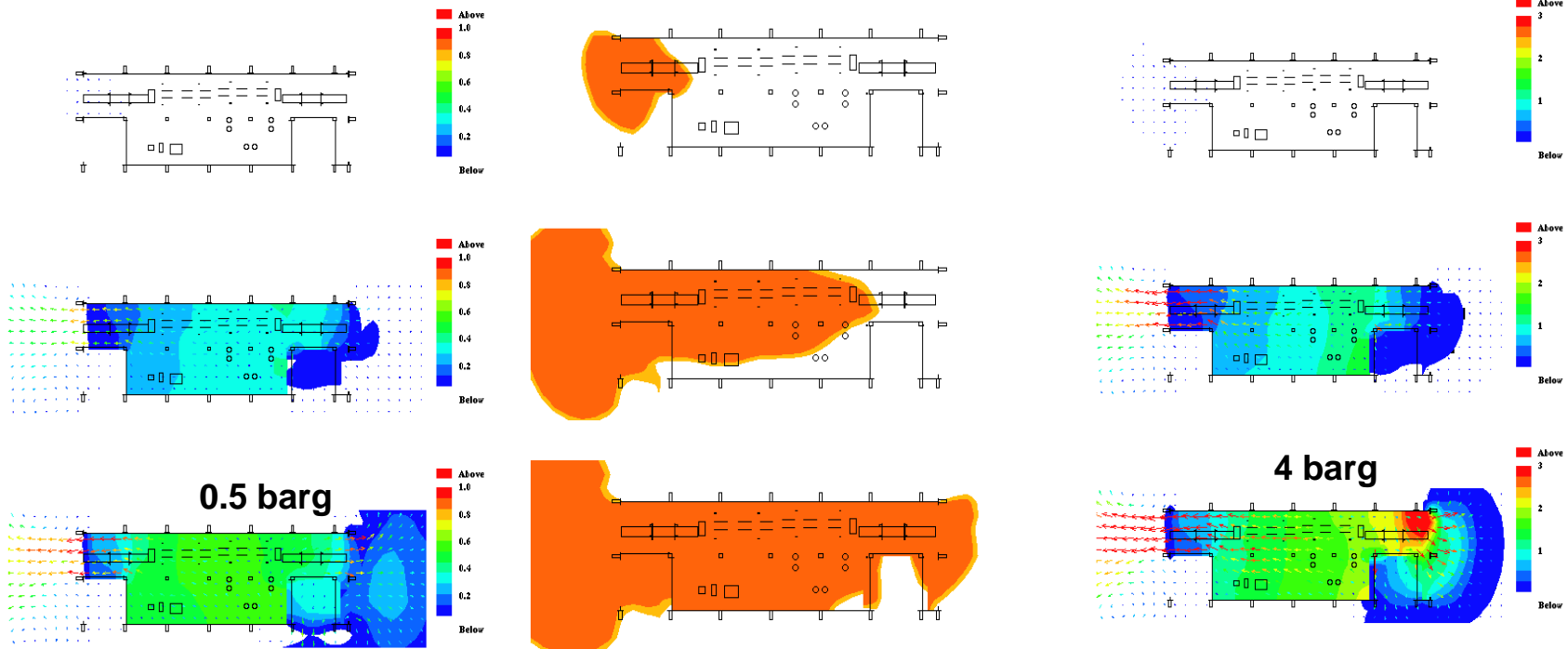
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Consider an explosion at an installation, a consultant predicts the following:



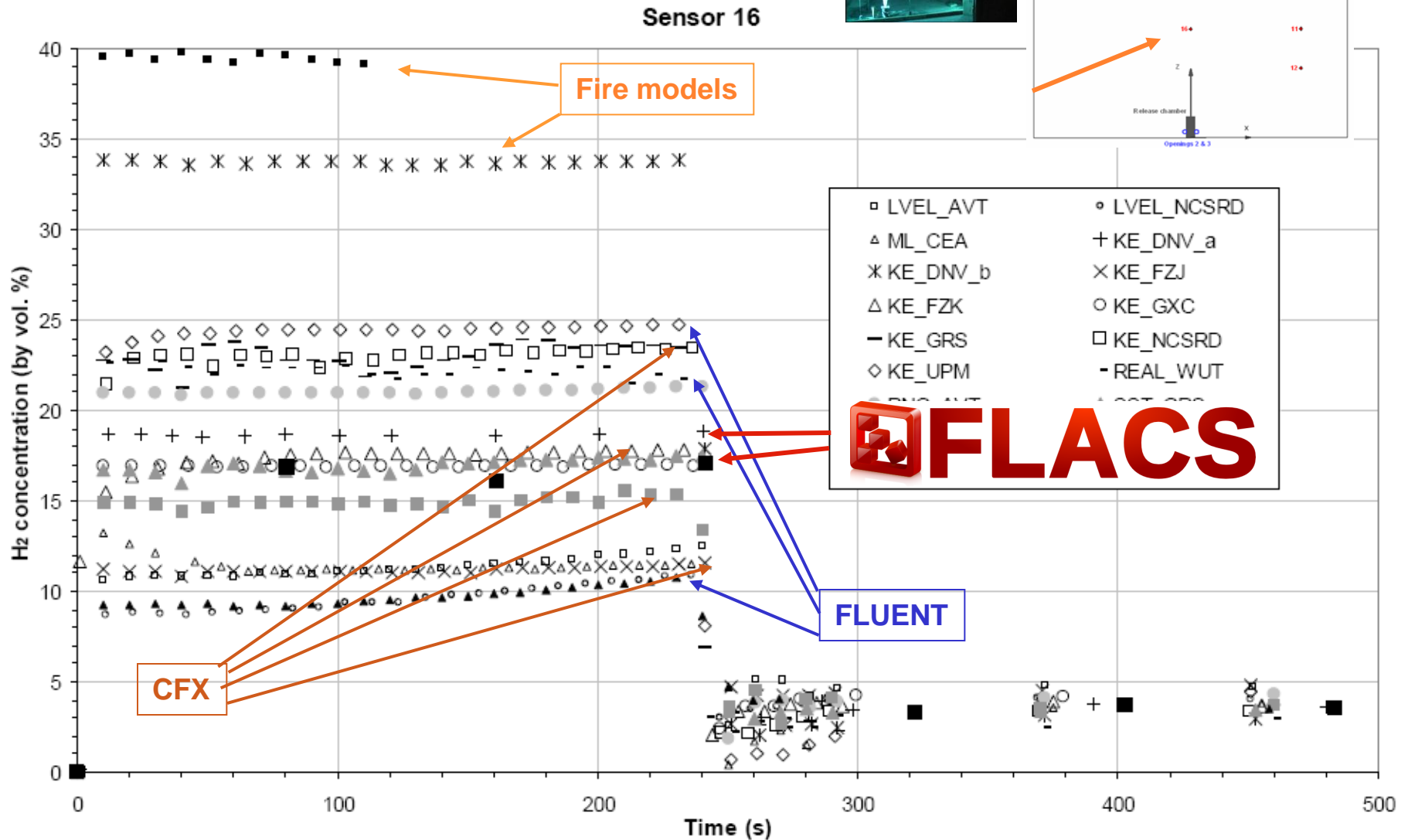
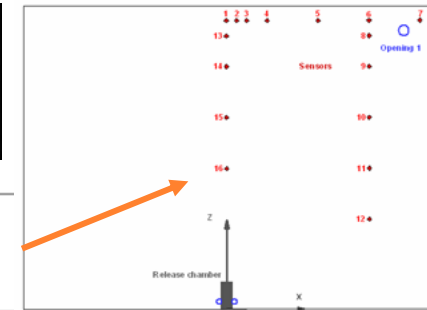
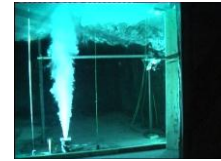
Or would you rather believe in this?

Difficult to know; we believe a good validation work must be performed, guidelines must be based on validation and followed by users

INERIS 6 HySafe blind benchmark



Published in Journal of Hydrogen Economy (Venetsanos)



FLACS advantages (4)

- Efficient and intuitive user interfaces
- In general short calculation times (on normal CPUs)

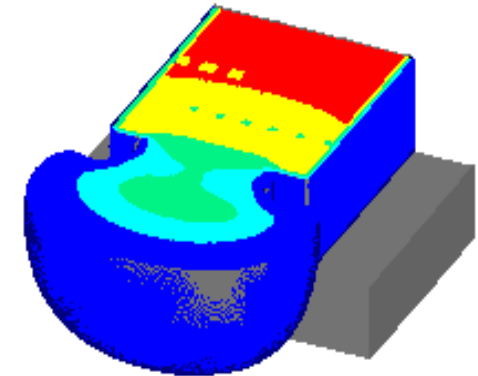
Hydrogen Summer School FLACS Workshop (50+ students)

- ✓ Everybody did 2-3 exercises in 3h
- ✓ Define geometry/grid/scenario, run simulations, study results



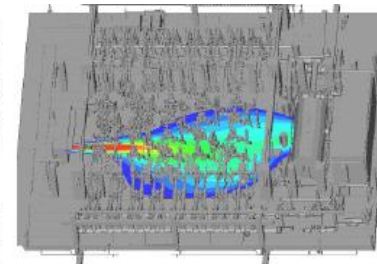
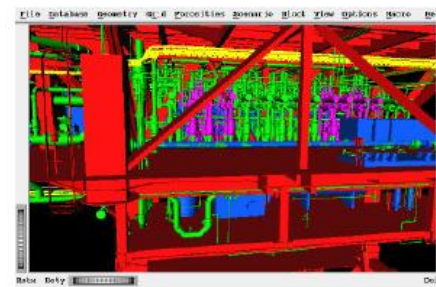
Basic simulation examples (< 20 geometry objects)

- ✓ Simulation geometry & scenario defined within minutes
- ✓ Usually interesting simulation results within 10-15 minutes
- ✓ Examples "months => minutes"



Real plant geometries can be handled fast

- ✓ Example of geometry brought to training course



Experienced users can be very efficient using FLACS

FLACS – advantages (5)

- Not CPU-pricing (like e.g. CFX/FLUENT) => enhances efficiency
- FLACS is widely accepted and by many also required!
- GexCon offer competent and efficient e-mail & phone support
- FLACS chosen by more than 70 organizations for its quality

FLACS Users Group (FLUG) meets 2-3 times a year

- ♣ Discuss challenges, increase confidence in use
- ♣ GexCon communicates development plans and news

Goals

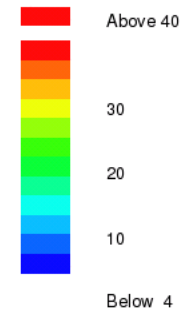
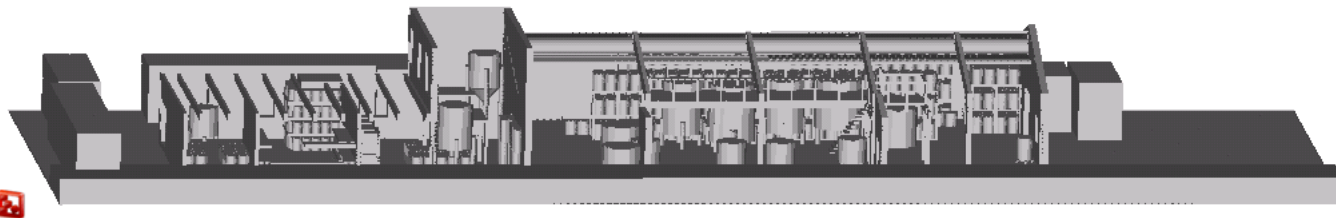
- ♣ End users shall be able to generate valid results in an efficient way
- ♣ To increase the use of CFD (and FLACS) for safety applications



UNDERSTANDING EXPLOSIONS

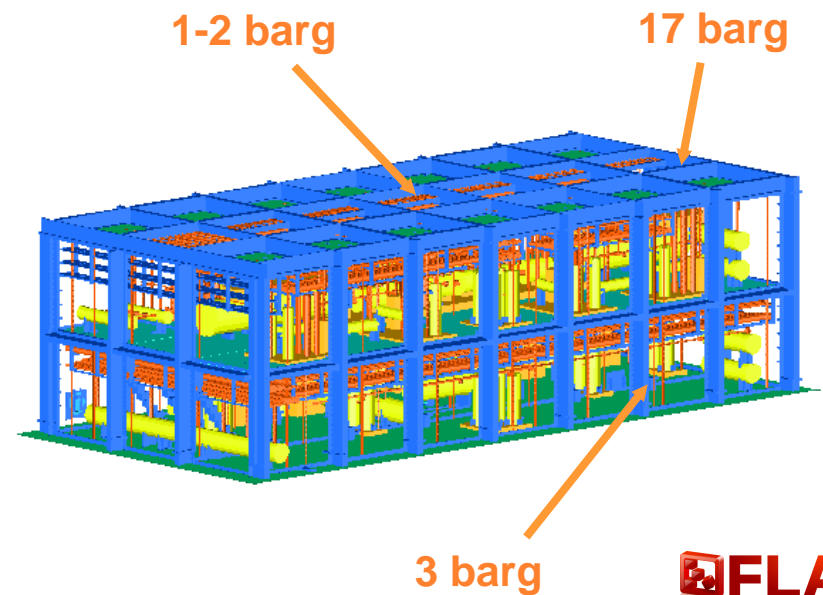
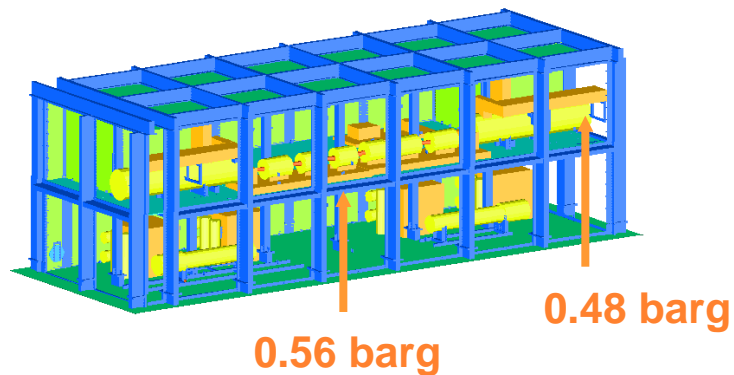
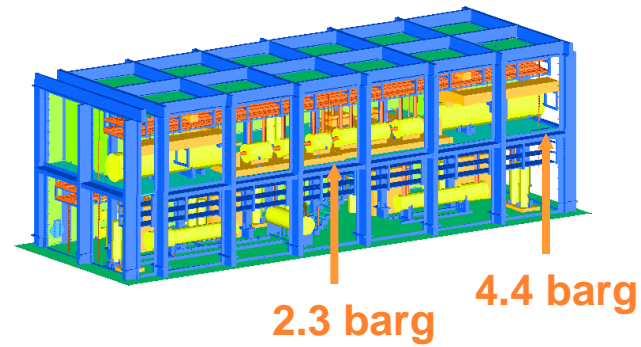
The following parameters are important for explosion strength

- Obstacle density (flow across obstacles accelerates flames)
- Confinement (removal of walls usually reduces pressures)
- Reactivity and concentration of flammables
- Flame distance / ignition location (severity may increase with scale)



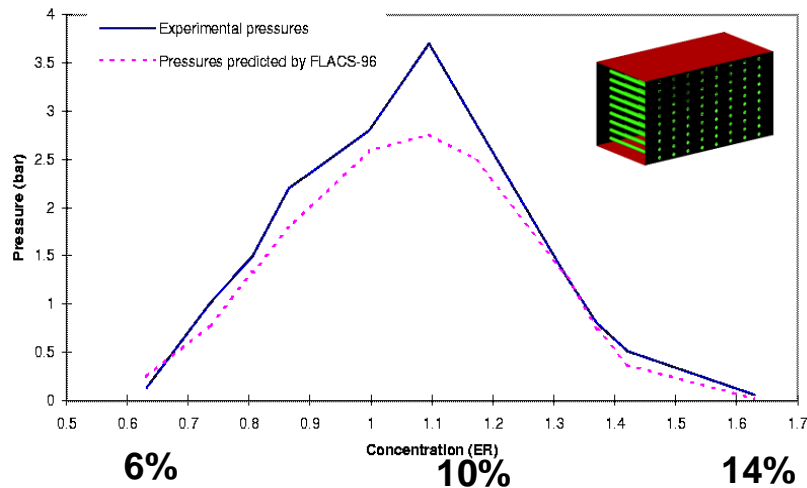
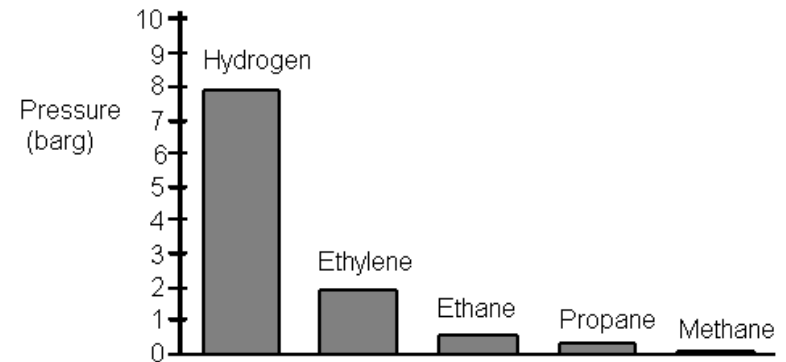
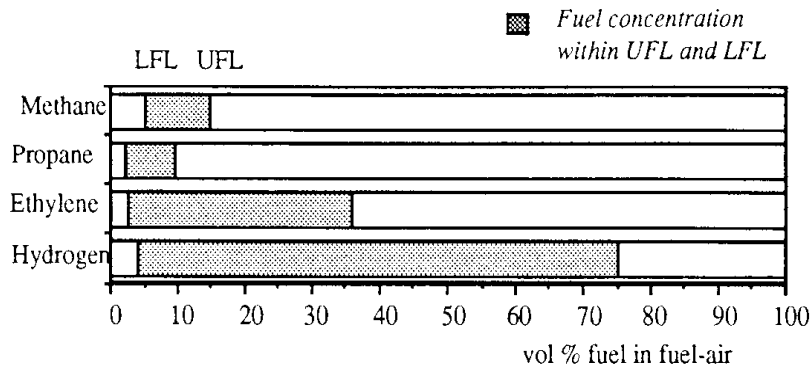
EFFECT OF IGNITION LOCATION

- Pressure varies with congestion and ignition location



GAS TYPE AND REACTIVITY

Significant difference in reactivity among gases and concentrations



Example difference between [propane](#) and [hydrogen](#)

REALISTIC RELEASES

Most explosions are far from worst-case (to be reflected in QRAs)

Worst-case reference



Realistic release



From GexCon test site (Similar observations at large-scale 2600m³)

Motivation for explosion studies

Identify dimensioning load i.e. Design Accidental Load (DAL)

- Early design phase or future modifications

Perform Risk Assessment, manage and minimize risk

- Comply with regulation or standards (e.g. ISO 13702, ISO-DIS 19901, Norsok Z-013, API RP 752)
- Company Internal Standards
- Evaluate risk implication of smaller modifications
- Assess effect of risk reducing measures (deluge, isolation, layout changes)
- Minimize losses

Norsok Z-013, Annex G (Publ. 2001, guidance)

G.5.2 Selection of simulating models

One should select an advanced CFD-type of model such as FLACS.

G.5.3 Selection of standard for modelling

The standard for modelling shall be selected according to requirements from the software supplier. This should be sufficient to the extent that effects observed in the Blast & Fire Project may be modelled.

Experience shows that it is vital to use a sufficiently detailed representation of the module geometry in the explosion simulations. Studies shall be performed on selected scenarios to show the sensitivity of the load to variations in the lower cut off limit for equipment size being included. Where detailed module geometries are not available, the input geometry shall be based on comparison with detailed geometries in similar modules or type of equipment.

The equipment densities used in the simulations shall be documented and compared to densities in similar types of modules.

INTERNATIONAL
STANDARD

ISO
13702

First edition
1999-05-15

Petroleum and natural gas industries —
Control and mitigation of fires and
explosions on offshore production
installations — Requirements and
guidelines

The combined effect of venting and layout modifications is complex and should be validated by blast calculations and/or experimental scaling. However, these effects can only be assessed quantitatively for specific situations. The degree of accuracy of these techniques is still being determined and improved, but the models may be used effectively to compare alternative layouts and effects of different location of ventilation openings.

Models used to calculate explosion loading should be validated as far as possible and allowance should be made for the uncertainty in the model.



DRAFT INTERNATIONAL STANDARD ISO/DIS 19901-3

ISO/TC 67/SC 7

Secretariat: BSI

Voting begins on:
2007-06-21

Voting terminates on:
2007-11-21

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION • МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ • ORGANISATION INTERNATIONALE DE NORMALISATION

Petroleum and natural gas industries — Specific requirements for offshore structures —

Part 3:

Topside structure

7.10.4 Explosion

Explosion scenarios shall be developed as part of the process hazard analysis. Assessment of explosions shall be performed in accordance with ISO 13702. If an assessment identifies that a significant probability ($>10^{-4}$) exists of an explosion exceeding the dimensioning load, explosion shall be considered as a design accidental event. Explosion as an accidental action may be treated using the techniques presented in Annex A.

Three major, controllable parameters influence the generation of explosion overpressure. Those are

- confinement by walls, decks and larger equipment,
- congestion due to equipment, piping, structure and cable trays
- size of combustible gas-air cloud formed by the hydrocarbon release

As part of the detailed explosion assessment process described in Figure 2, confinement shall be suitably represented, congestion shall be sufficiently detailed and representative gas-air clouds used. The latter requirement poses the largest problem. Two possible approaches are to use:

- worst-case gas clouds "stoichiometric mixes", where it is certain or at least highly probable that the resulting actions are conservative
- a distribution of gas clouds with associated probabilities, where the resulting actions and their probabilities can be presented as a series of curves showing the probabilities of exceeding a range of overpressures. This approach is particularly suitable when probabilistic acceptance criteria are set, as required in 7.10.1 above.

Management of Hazards Associated with Location of Process Plant Buildings

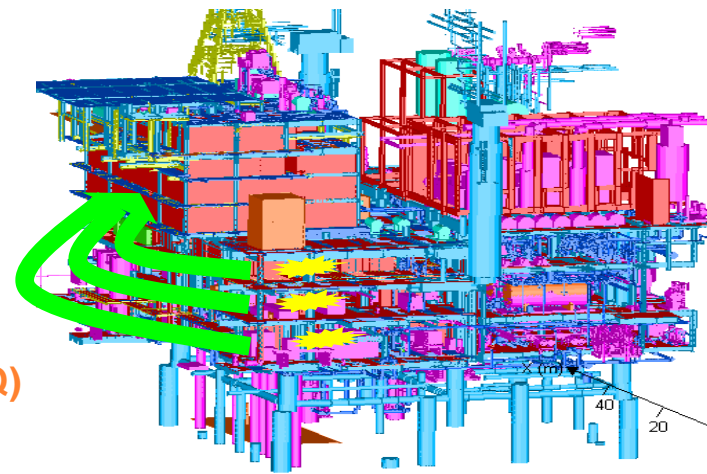
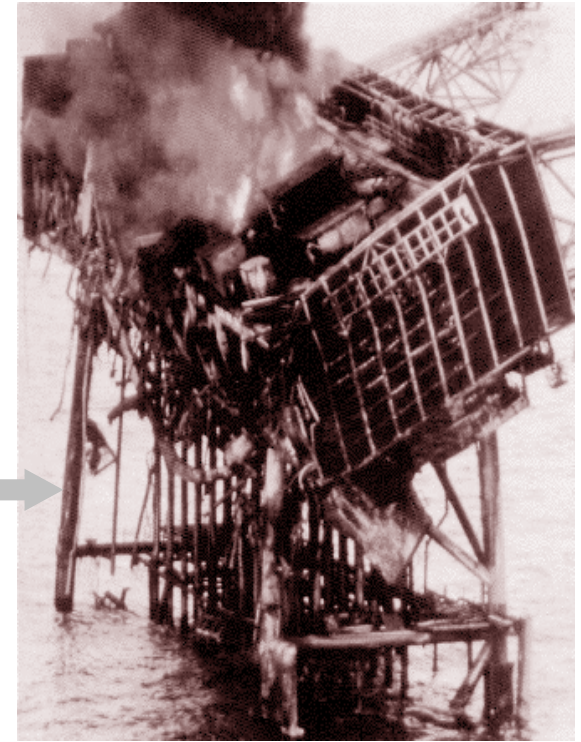
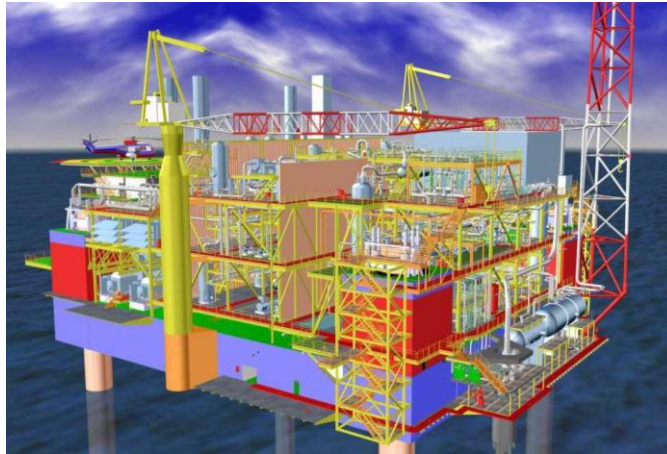
API RECOMMENDED PRACTICE 752
SECOND EDITION, NOVEMBER 2003

There are several methods available for calculating explosion overpressure, such as the TNT-equivalency, Multi-Energy, and Baker-Strehlow. Additional information on explosion calculation methods is available in Section 4-3 of *Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs*, published by the Center for Chemical Process Safety (CCPS).

- Determine the explosion loading (overpressure and duration) for each event for each target building using the TNT-equivalency, Multi-Energy, Baker-Strehlow, or other method.

Risk philosophy ISO DIS 19901

- Offshore: one event must not lead to escalation in other areas
- Risk barriers – blast walls
- Criteria: return frequency 10^{-4} /year



Loads from different sources (e.g. on LQ)
should be handled in a consistent way

Examples use of FLACS:

Explosion analyses

- Worst Case (3-10 explosion simulations with 100% filling of module/room)
- Realistic Worst Case (5-50 dispersion + 3-10 explosion simulations to bound worst-case)
- Probabilistic (10-20 ventilation, 50-200 dispersion + 30-50 explosion simulations)
 - Risk = probability x consequence
 - Probability aspects: Leak frequency, weather data, ignition modeling

Other analyses

- Detector studies
- Exhaust/helideck studies
- Hydrogen
- Release from stacks and pressure relief devices
- Releases of flammable or toxic substances
- LNG spill, fog-studies
- Reconstruction of accidental leaks or explosion

Probabilistic explosion analysis

1. Ventilation simulations

- Provide ventilation rates inside the module under different weather conditions
- Correlated with weather statistics

2. Dispersion simulations

- Provide a representative selection of release scenarios
- Correlated with leak frequency data

3. Explosion simulations

- Provide a representative selection of explosion scenarios
- Frequency of ignited cloud sizes from dispersion study + TDIIM

4. Risk Calculation

- Produce probability-of-exceedance curves (pressure and/or impulse)
- Followed by structural assessments if requested
- Effect of mitigation measures (deluge, layout modification, isolation)

=> Often more to gain to optimize ventilation / dispersion than explosion study

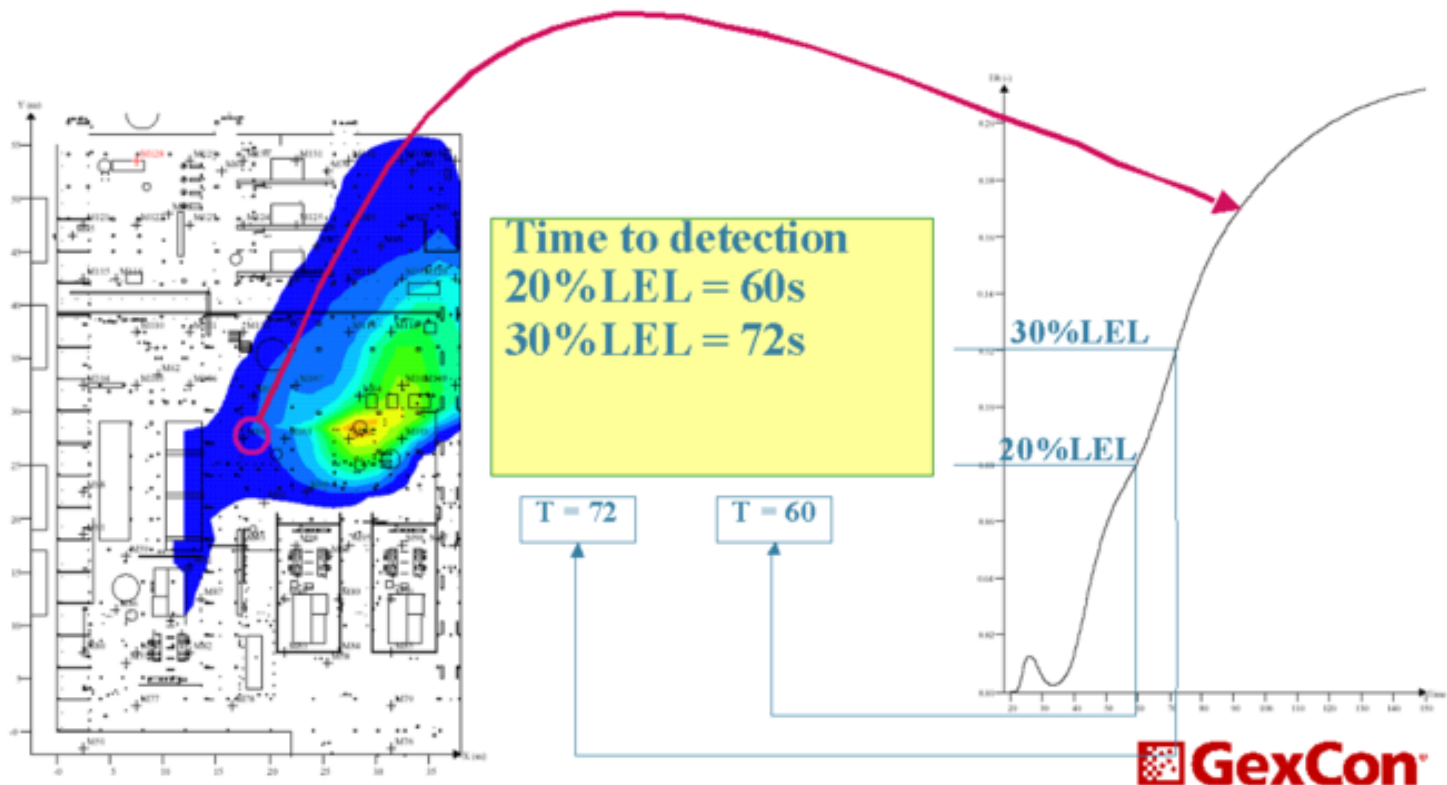
Gas Detector Optimization Studies

Example study:

Several hundred gas sensor locations are evaluated against 100s of dispersion/wind calculations

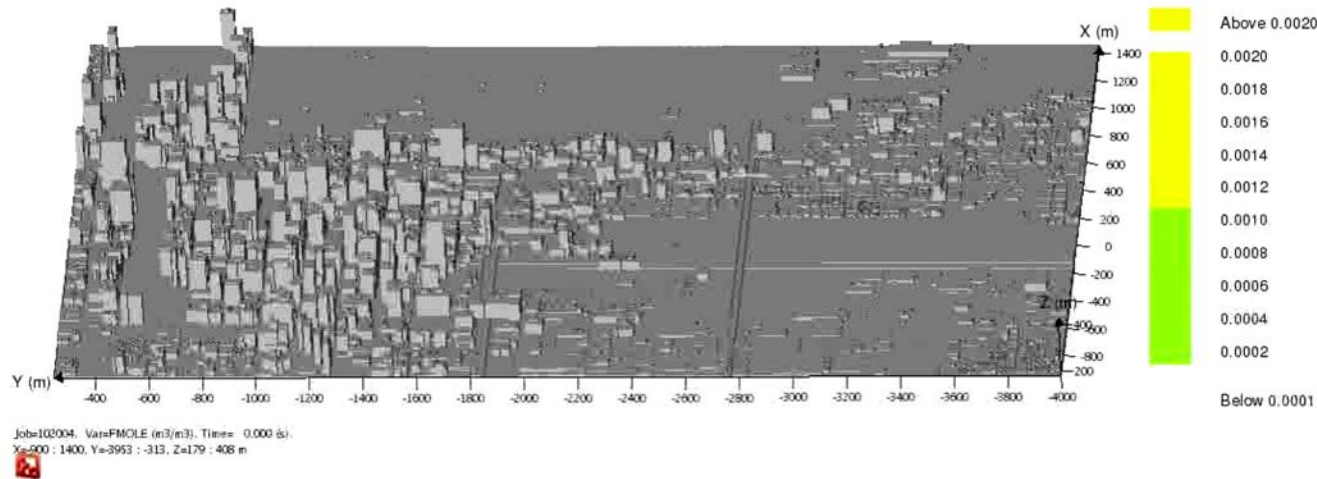
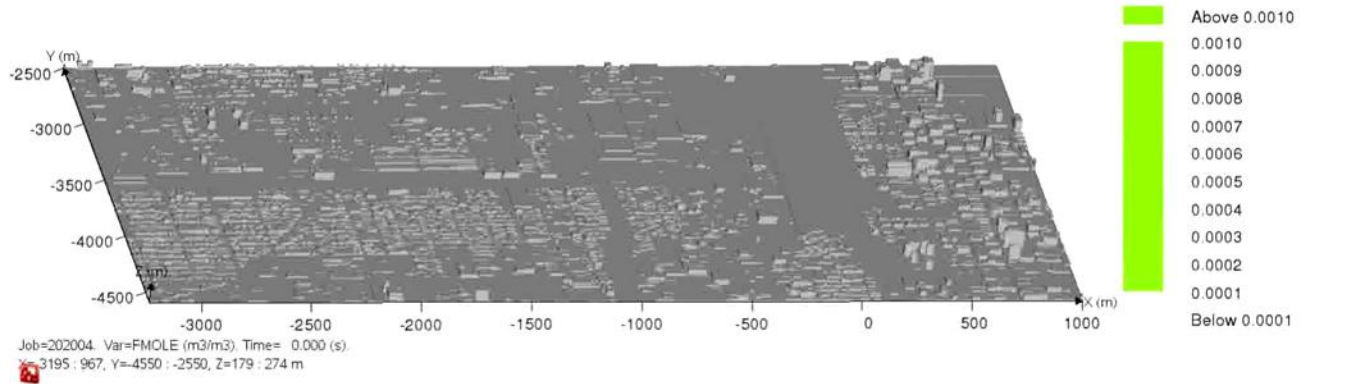
⇒ What combination of 15 sensors will quickly detect (2 sensors) before gas clouds grow large

Time to detection



Release during transportation

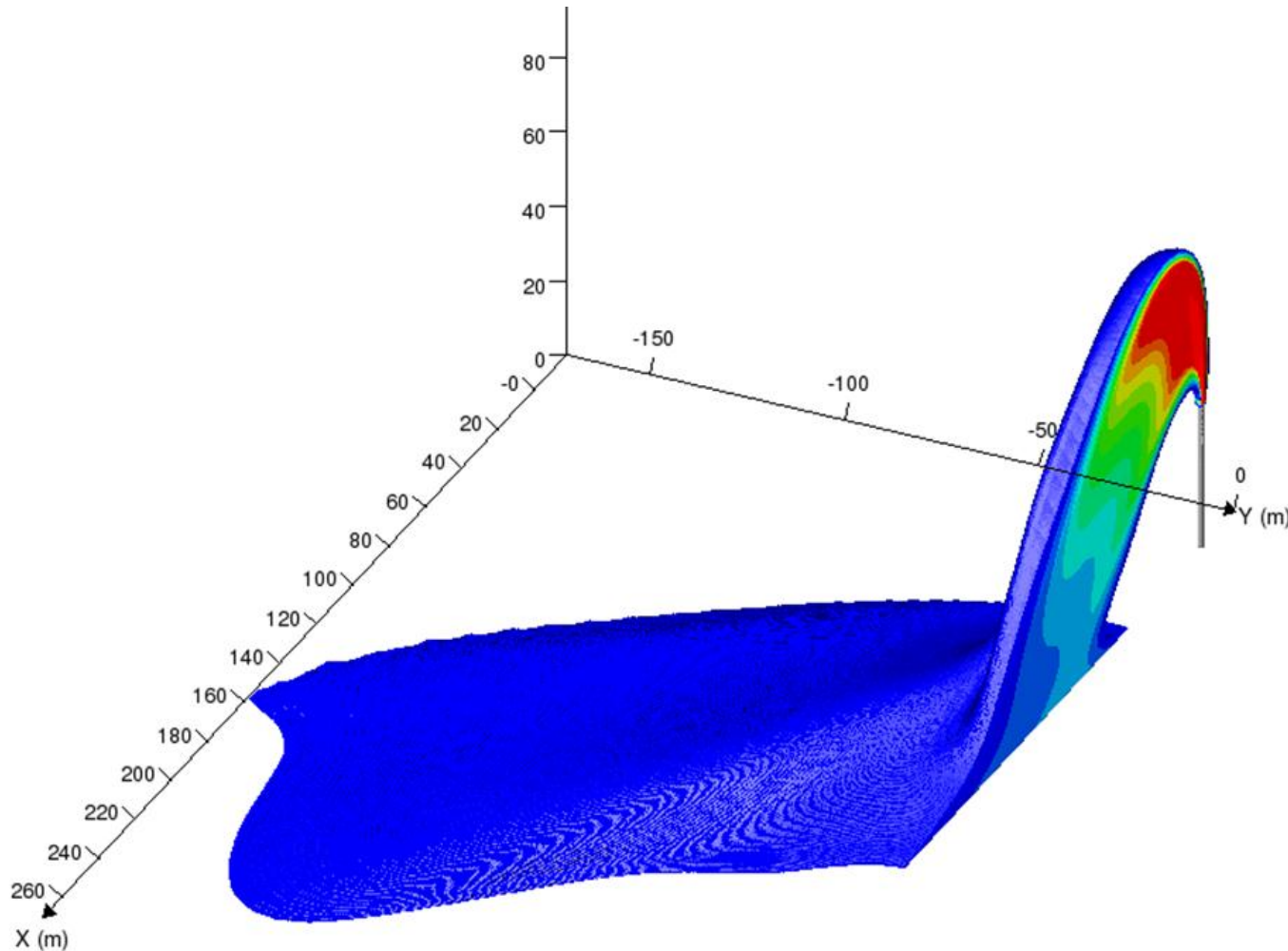
Example study:
Flashing release of chlorine from a railcar



Stack release, flammable or toxic gas

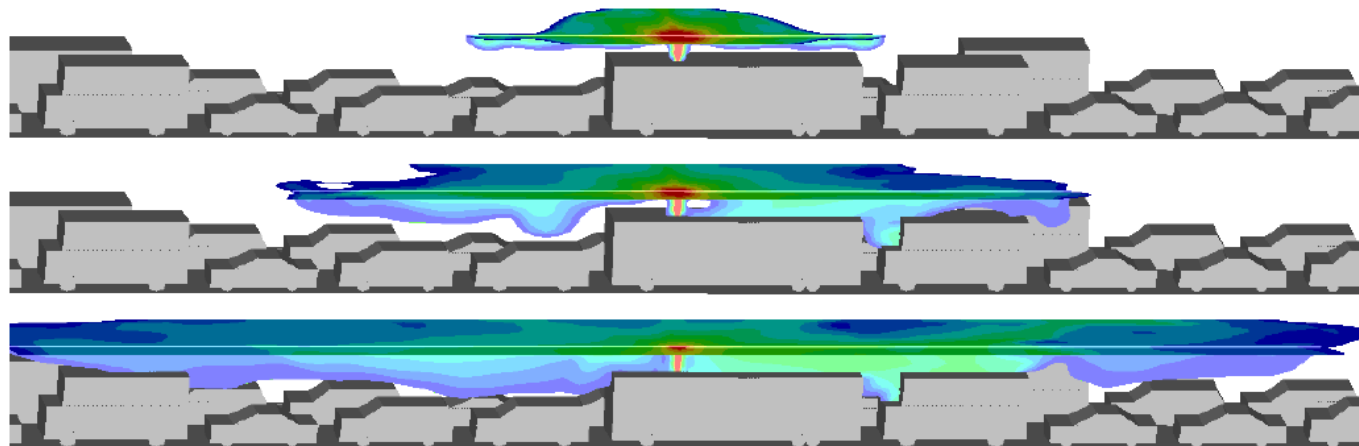
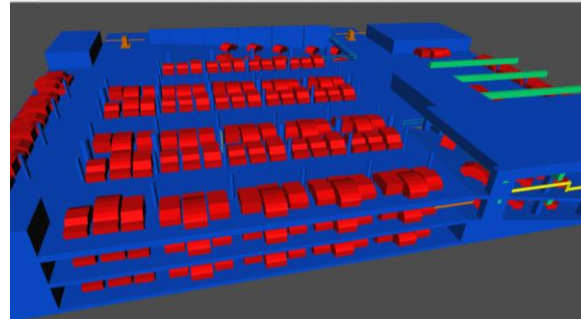
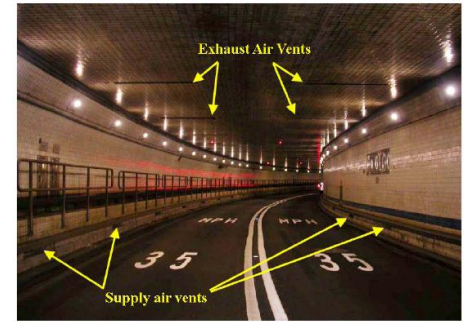
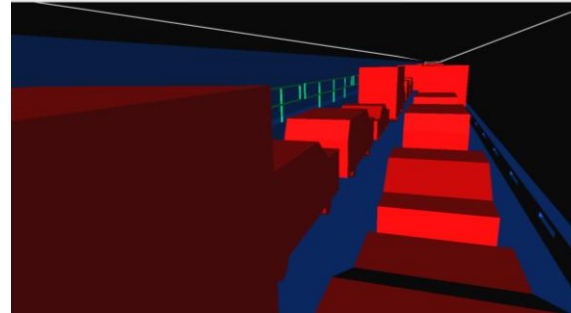
Example study:

CO₂ stack, can concentrations in near field be above threshold limits during low wind



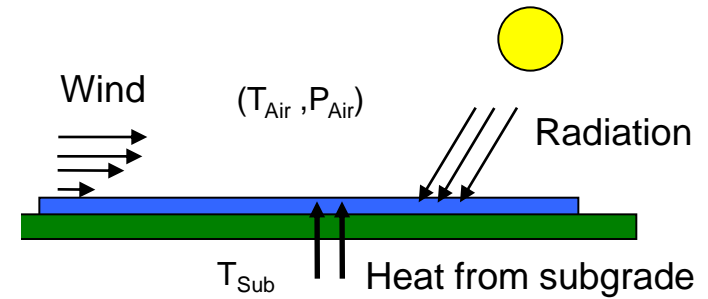
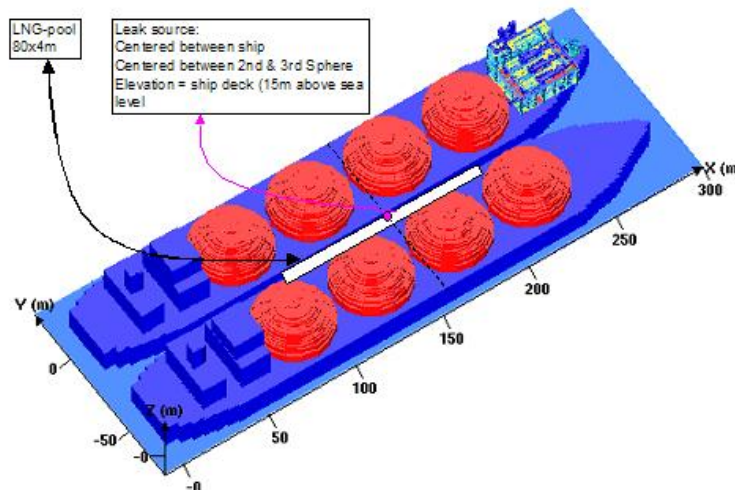
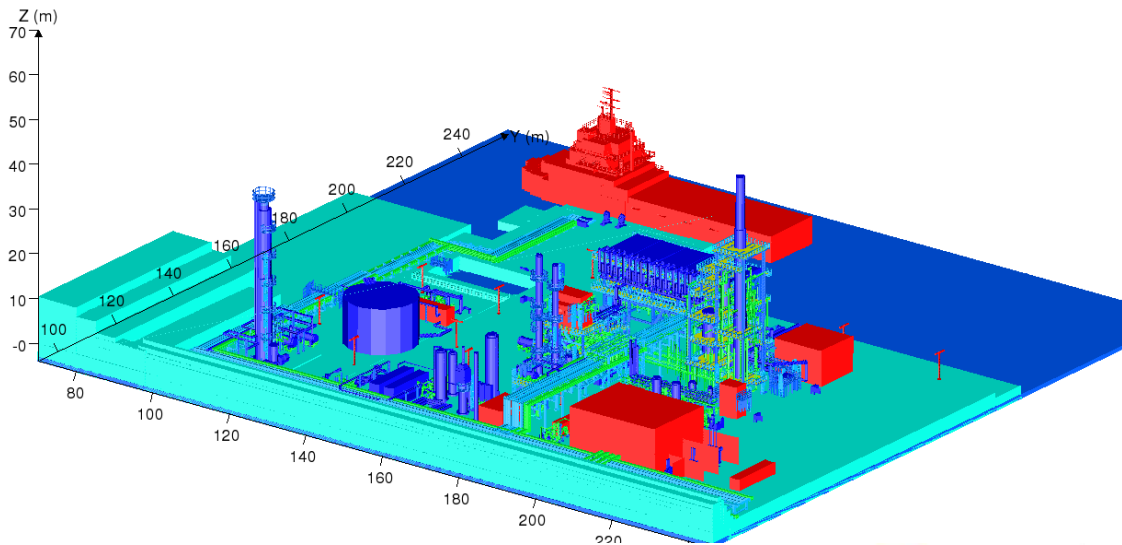
Release during transportation

Example study:
Release of various flammables
or toxic substances in tunnels
and parking garages.



LNG Studies

- GexCon has simulated all NFPA Model Evaluation Protocol scenarios (33 experiments)
- Pool spill, spread and evaporation models improved



Evaluating Vapor Dispersion Models for Safety Analysis of LNG Facilities Research Project

Technical report

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April 2007

Accident investigations GexCon/FLACS



Spanish coal mine (1999)



Oslo theatre (1999)



Piper-Alpha (1988)



Petrobras P-36 (2001)



Buncefield (2005)



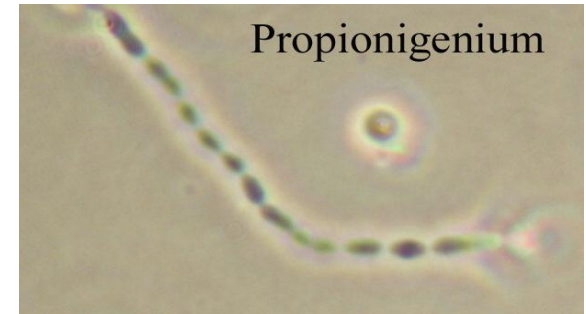
TWA-800 crash (1996)

Accident investigations GexCon/FLACS

Residential home Scotland 2003



Tank explosion 2006



Tank explosion Norway 2007



Sarpsborg (2000)



Conclusions

FLACS is the preferred tool for explosion safety evaluations

- Geometry and scenario can be taken into account
- Possible to combine ventilation, dispersion, explosion and mitigation
- Possible to build an understanding of past accidents
- Continuous and significant investment in FLACS R&D

Interested to learn more about FLACS?

Consider to join the next 3-days' training course and receive a 1 month evaluation license afterwards.

For more information please contact

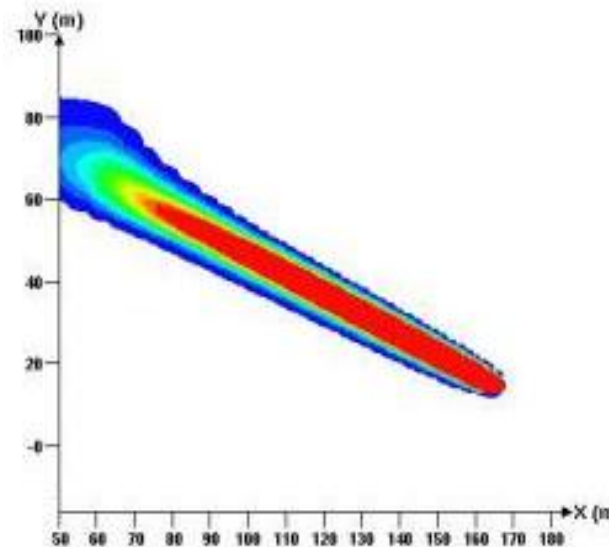
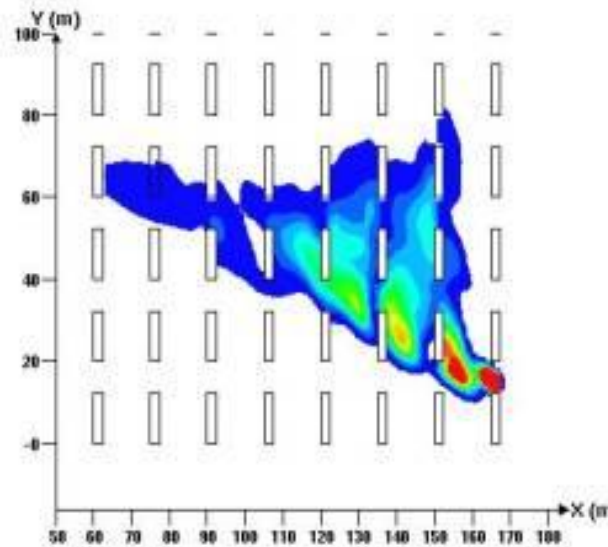
flacs@gexcon.com

<http://www.gexcon.com>



Release and dispersion are important

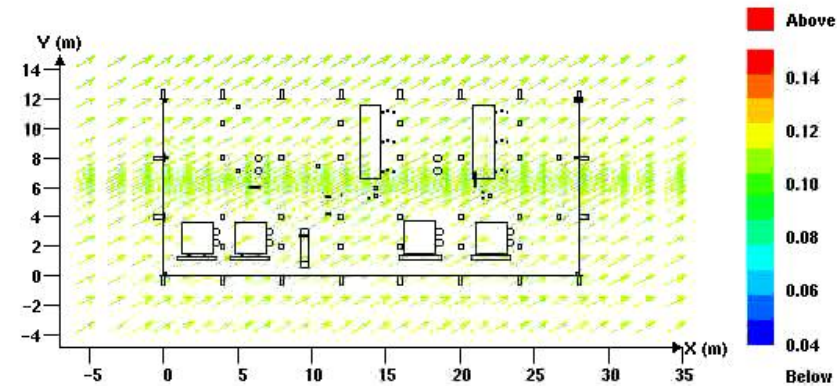
- Prediction of gas clouds formed as a result of release and subsequent dispersion is a pre-requisite for accurate estimation of explosion loads
- Integral models such as those used in simplified tools like Phast can also give inaccurate predictions about dispersed gas clouds
 - Effect of geometry is generally ignored



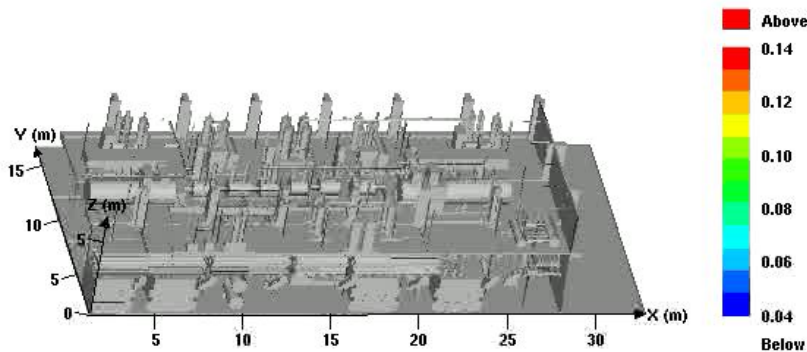
Example simulation

Simulation 17: Steady state far from most dangerous situation

=> Transient simulations are needed!

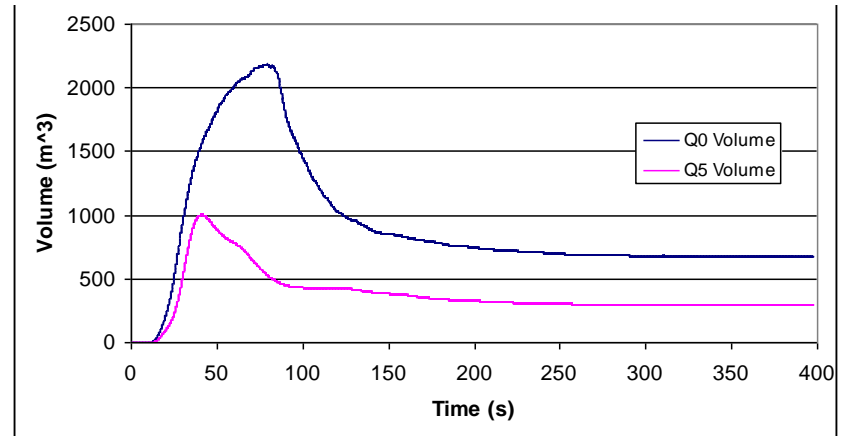


Job=121703.
Time= 0.000 (s), IJ plane, K=3

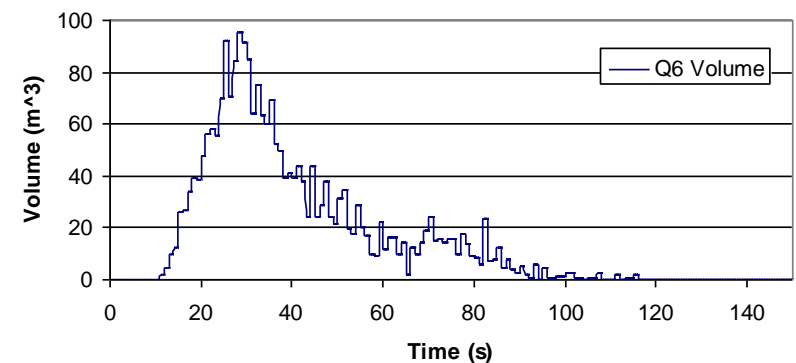


Job=121703. Var.=FMOLE (mol/mol).
Time= 0.000 (s), I=14-36, J=13-29, K=1-9.

Volume (flammable) and Equivalent stoich.

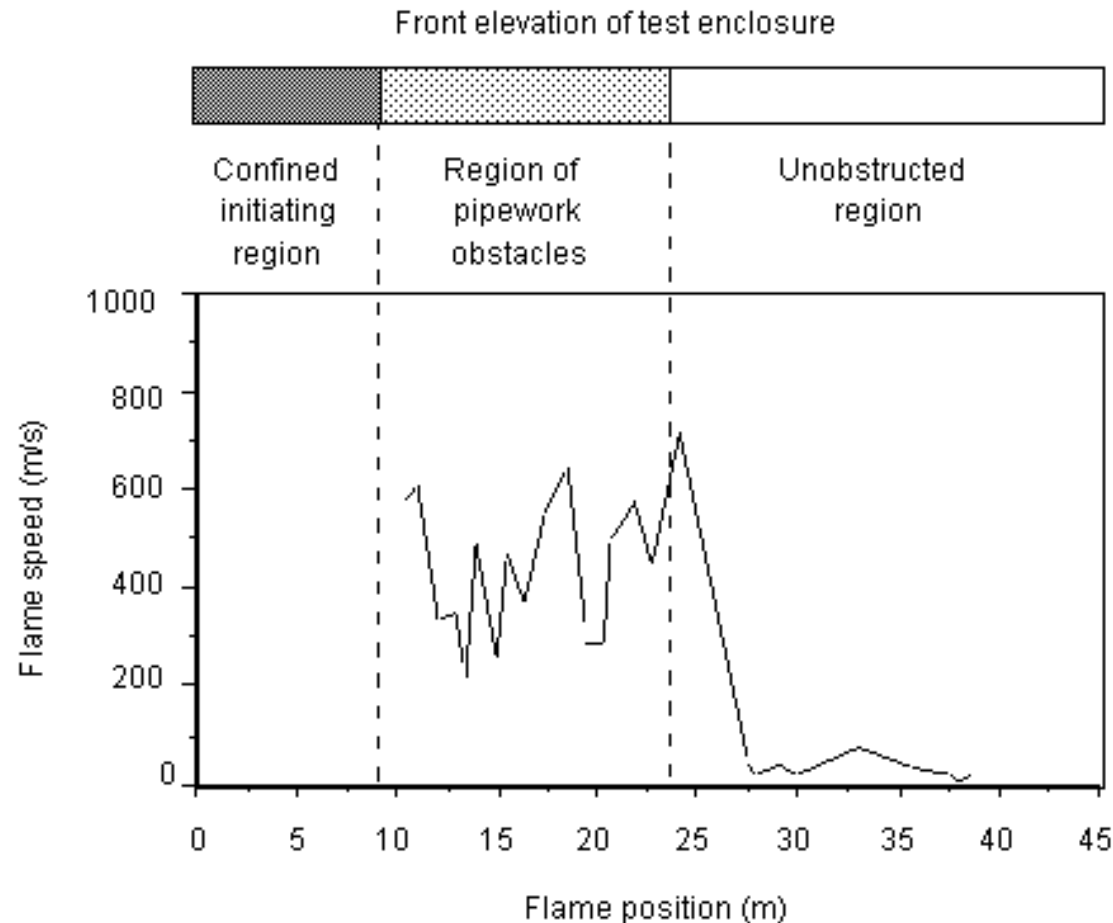


New volume to see flammables



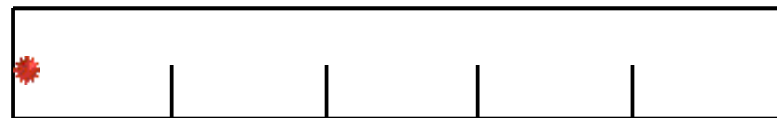
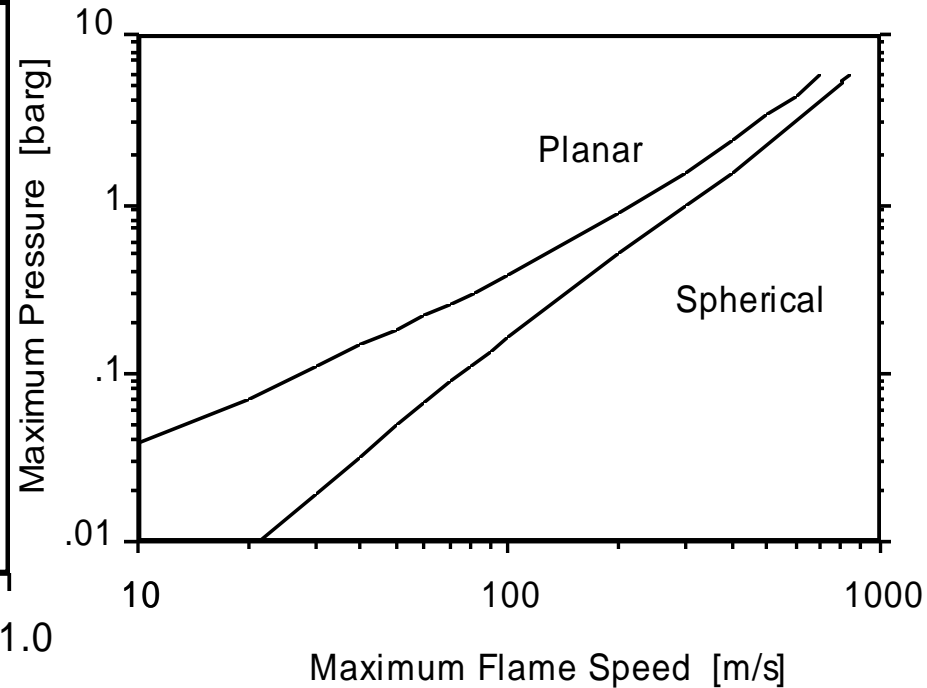
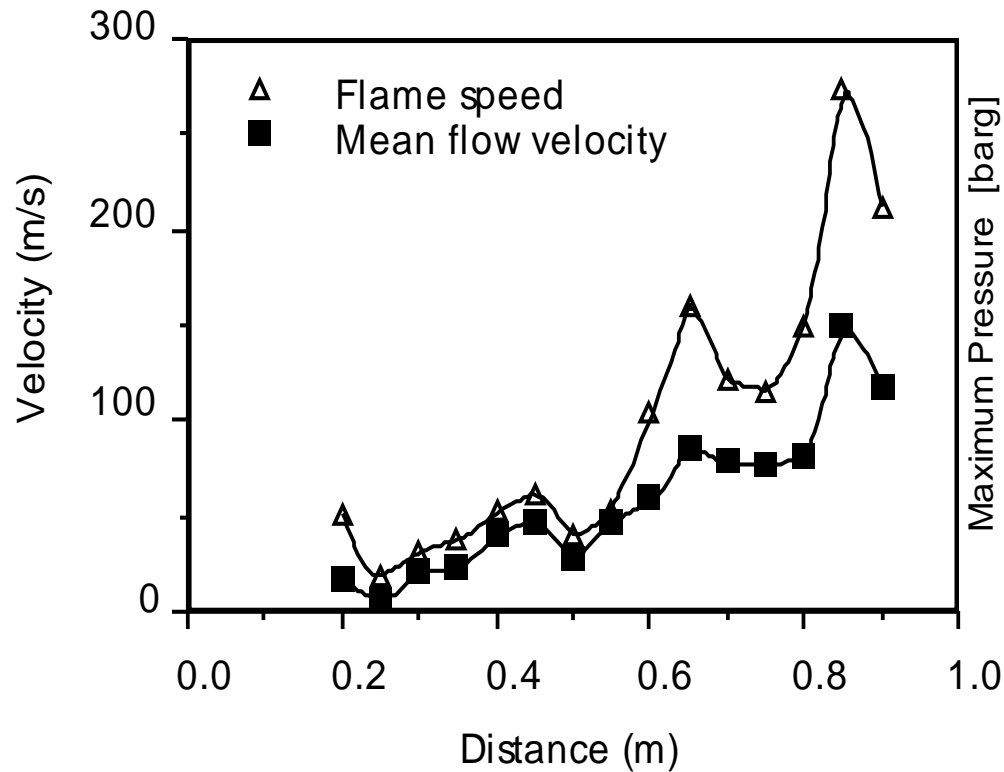
Ignition at 30-40 seconds most likely AND most dangerous

Experiments – obstructed vs. non-obstructed



Flame acceleration

Pressure



Front elevation of test vessel

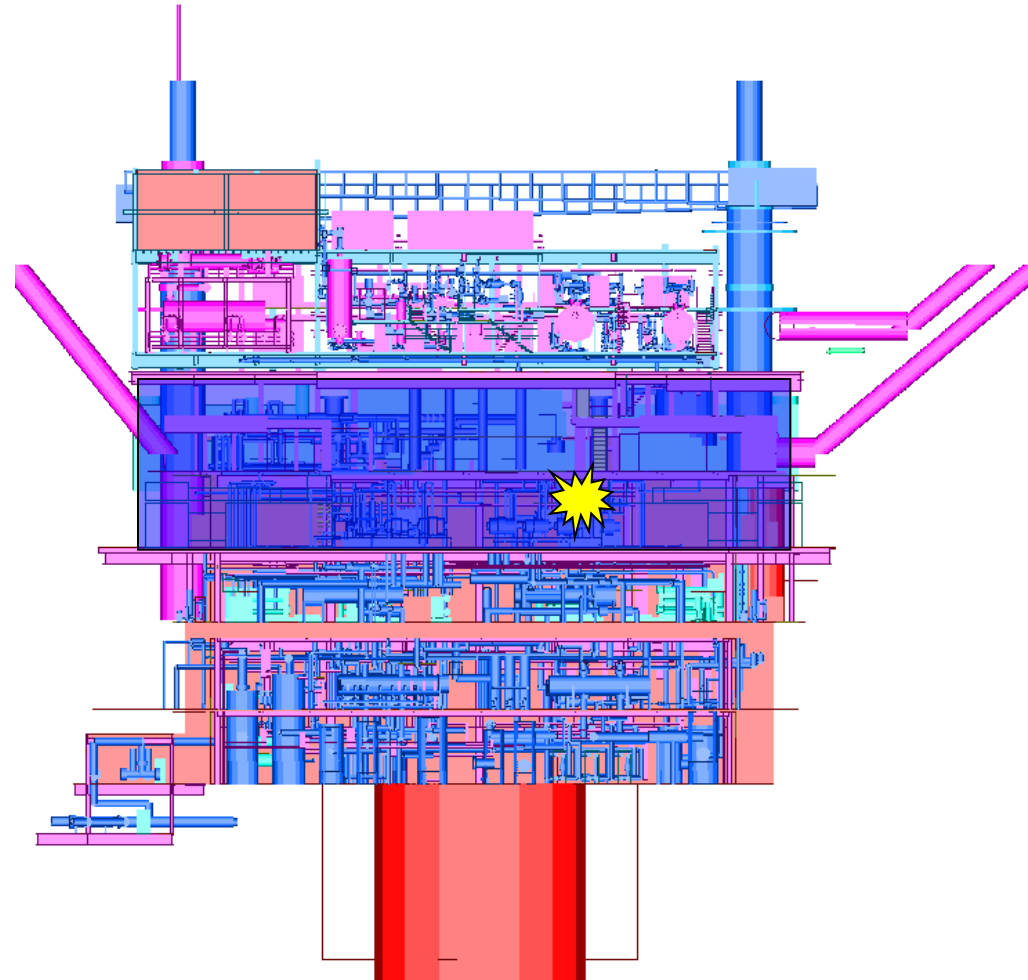
Gas explosions in industrial installations

- Main parameters affecting the course of an explosion:
- Gas cloud size and location upon ignition; Moment of ignition
- Number / orientation / location of equipment, pipes & structural components \Rightarrow "Degree of congestion"
- Vent openings / panels (size and location) \Rightarrow "Degree of confinement"
- Gas concentration, inhomogeneities
- Gas type (reactivity)
- Active mitigation measures



Worst case explosion analysis

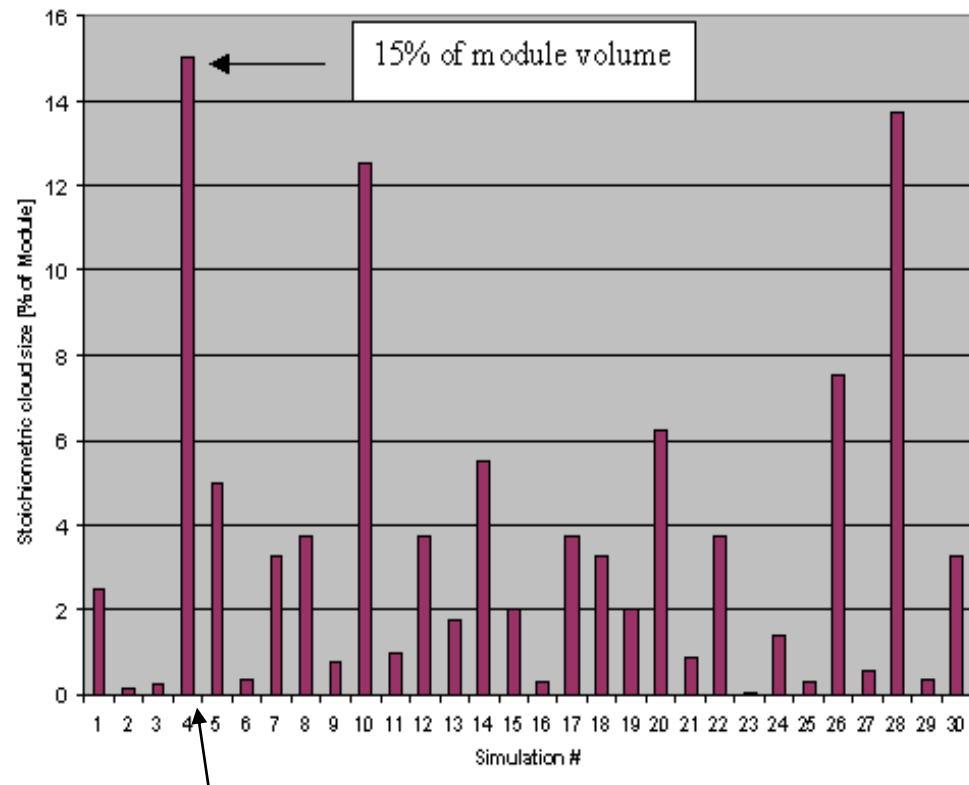
- 100% filling
- Typically 4-5 ignition points
- Very conservative
- Simple and quick
- Applicable where explosion risk is low (yes/no question) or load can easily be handled
- High congestion areas
 - Load very high
 - impossible to design for



Realistic worst case explosion analysis

- Objective: assess the maximum realistic overpressure that can be experienced
- How:
- Limited number of dispersion simulations (looking for worst case clouds)
- Limited set of explosion simulations based on the dispersion simulations

Cloudsizes identified
in dispersion simulations



Cloudsize used in explosion
scenario used for exp

Blast decay methods

- Curves for estimating explosion overpressure in the far-field as a function of distance to the cloud centre
- TNT equivalency method: Pressure load by explosions in the far-field is predicted as an equivalent load from TNT-explosions
 - TNT equivalency factor must be defined (can be very difficult)
- Multi-Energy and Baker-Strehlow methods: Graphs for estimating overpressure at a given distance to cloud centre
 - Function of source strength / maximum flame speed

