Institution of MECHANICAL ENGINEERS

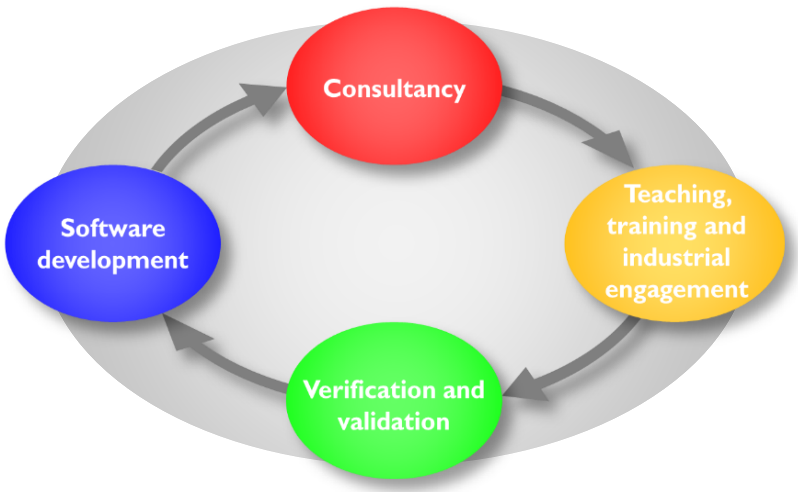
Enabling improved analysis data for blast protection of offshore structures

Steve Howell and Simon Feven – 8th December 2015

abercus

Abercus

Abercus is an independent, privately-owned consultancy specialising in advanced engineering simulation within the energy sector – computational fluid dynamics (CFD), finite element analysis (FEA), the development of bespoke software tools and teaching/training.



Acknowledgements

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Agenda

- Acknowledgements
- Introduction
- Probabilistic explosion assessment
- Improving the integration of analysis data
- EXCGEN – a software tool to enable an integrated approach
- Sharing/democratisation of analysis data
- 3D risk assessment
- Selection of representative 10^{-4}/yr events
- Probabilistic structural response
- Summary.

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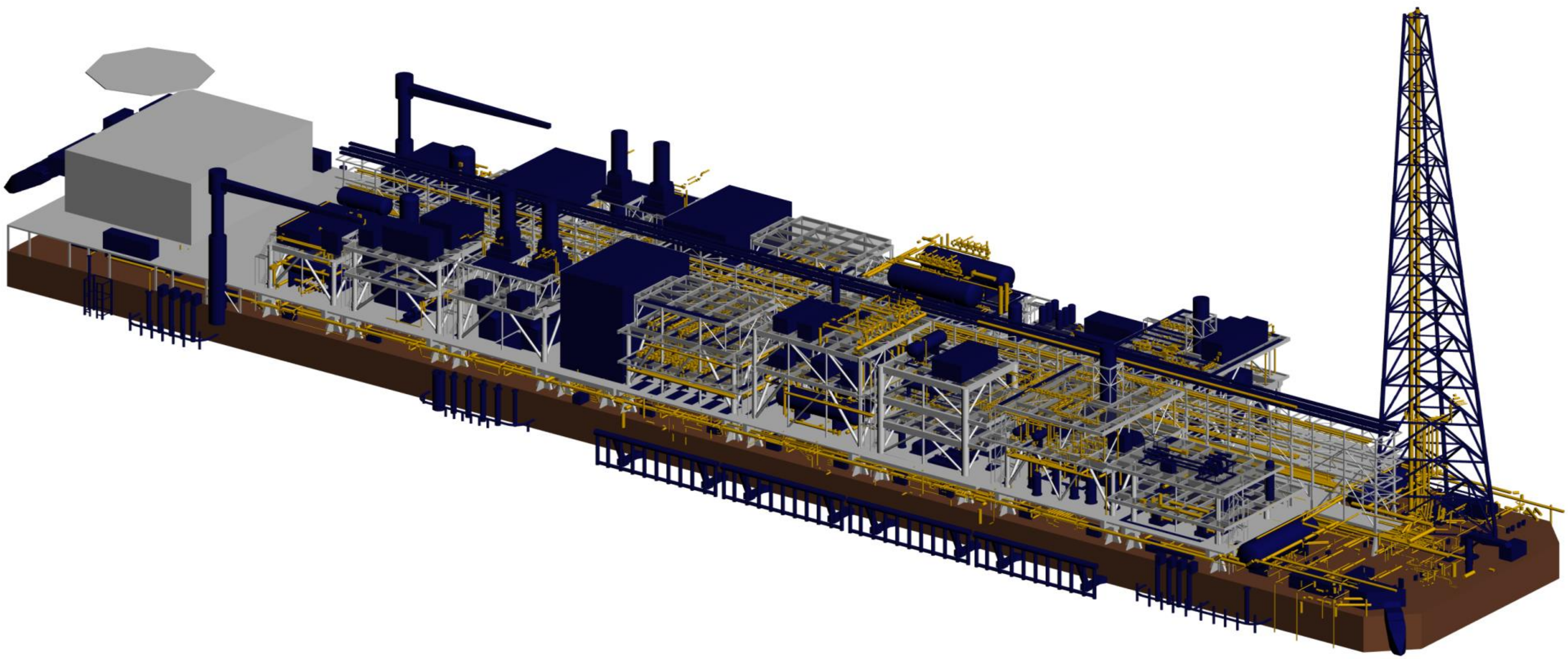
Introduction

- When designing for blast it is necessary to quantify the magnitude of the design accidental loads (DAL) and CFD is often used to simulate explosion events for this purpose
- When determining the DALs there is often a large amount of useful analysis data that is generated but not used
- This paper introduces a method aimed at improving the integration of explosion and blast analysis data in structural design to enable improved and safer offshore facilities
  - Sharing and associated democratisation of analysis data – sensitivities
  - 3D risk assessment
  - Probabilistic structural response.

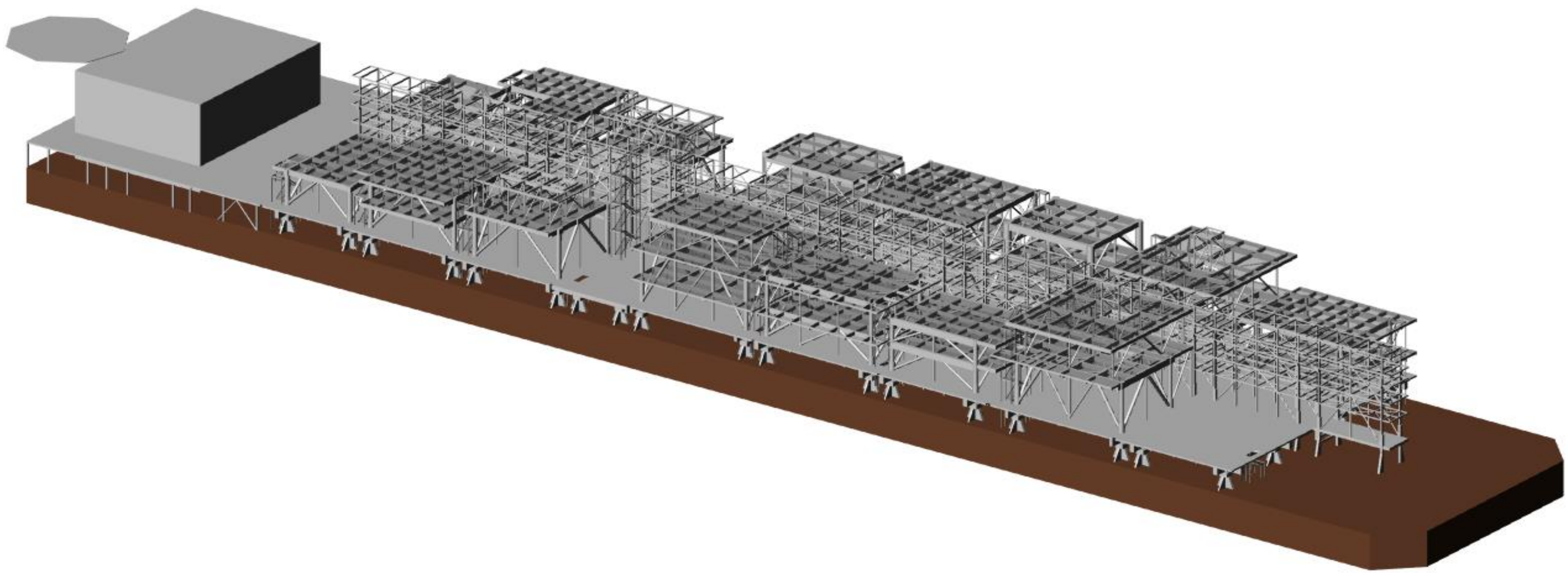
Introduction

- Computational fluid dynamics (CFD) is a numerical approach used for solving the governing equations for fluid flow
- CFD is widely used in many industries and is becoming increasingly used in the offshore and energy sectors
- With the CFD approach, the flow domain is divided into many non-overlapping volumes and the governing equations are solved iteratively for each cell …

Introduction



Introduction



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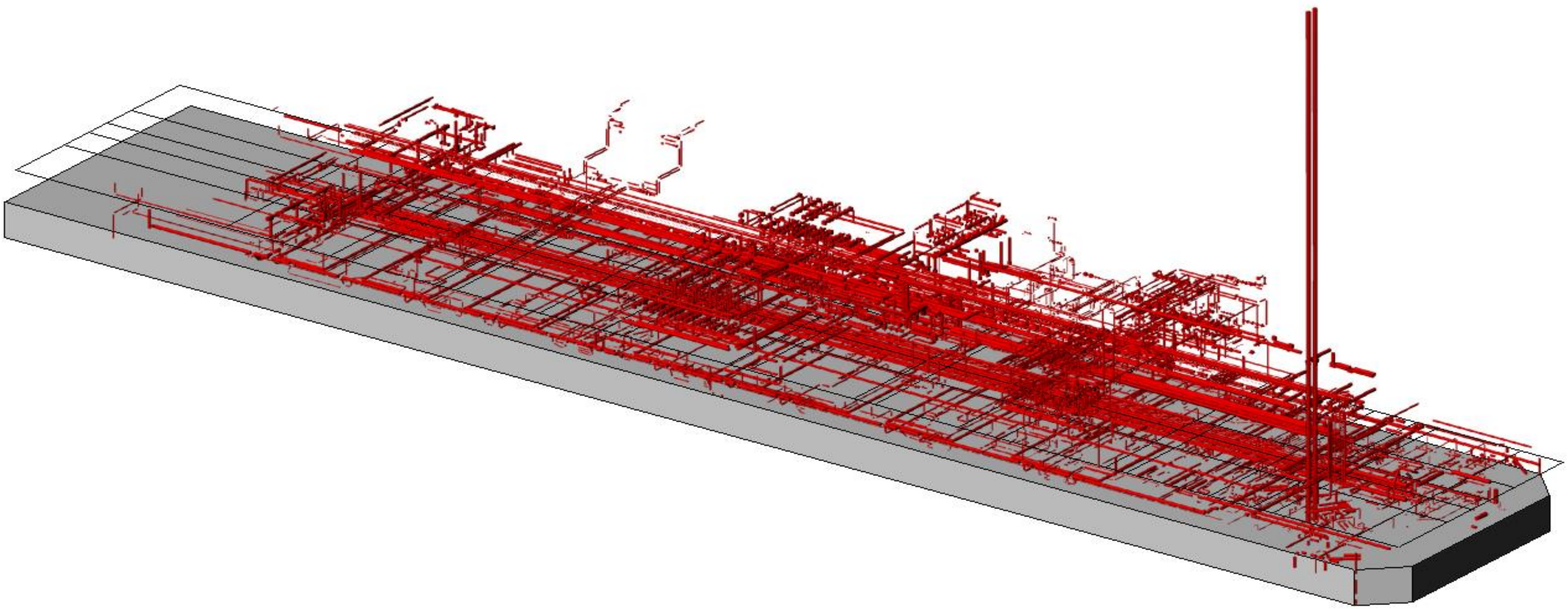
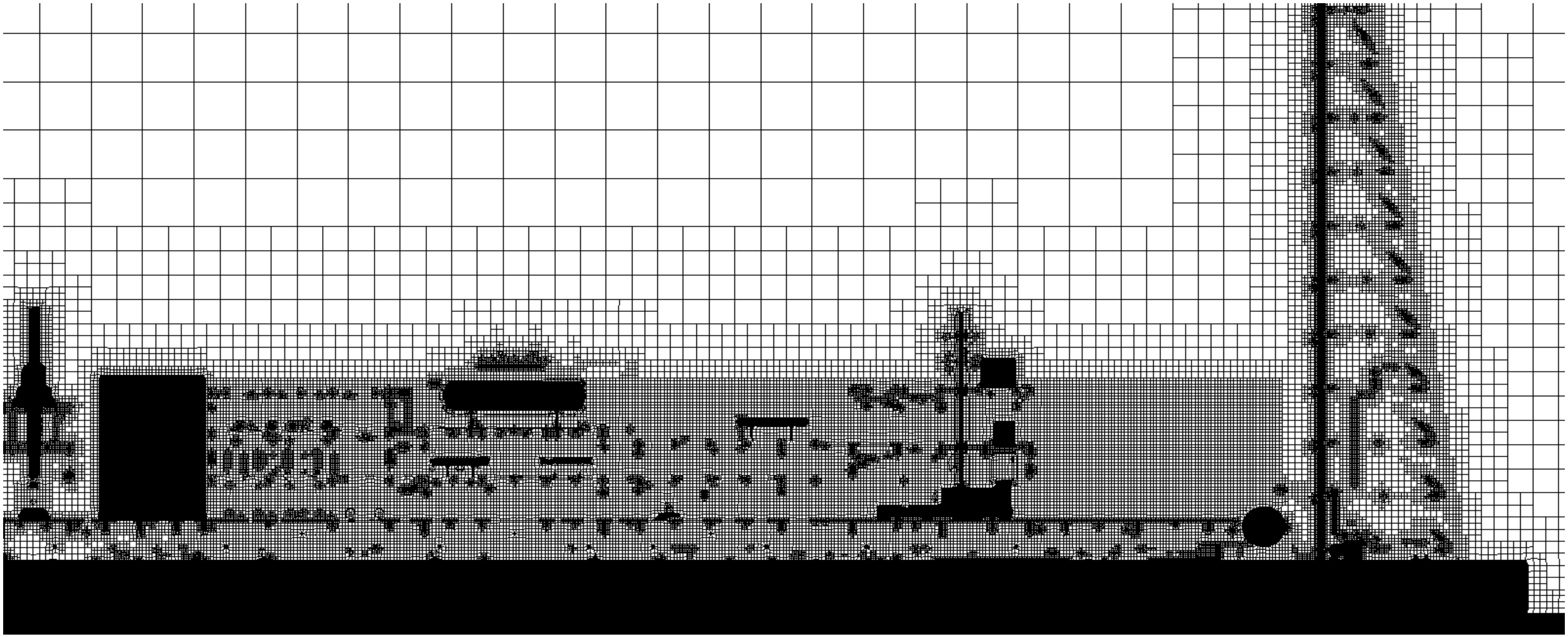


Introduction



Introduction

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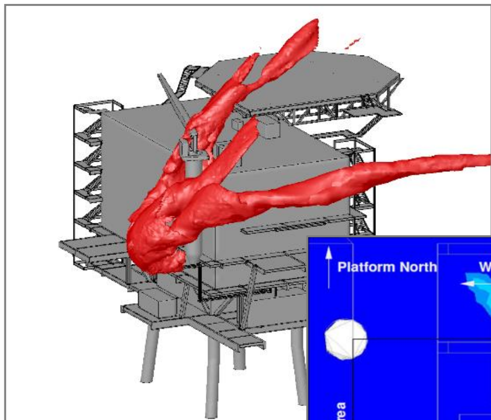
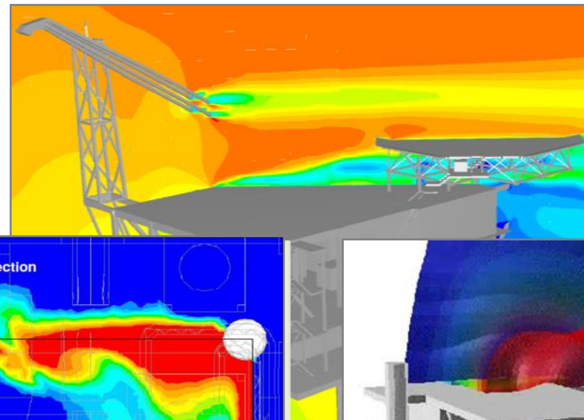
- CFD is widely used in many industries and is becoming increasingly used in the offshore and energy sectors
- With the CFD approach, the flow domain is divided into many non-overlapping volumes and the governing equations are solved iteratively for each cell …
- … and then the governing equations describing fluid flow are solved iteratively for each cell.

Introduction

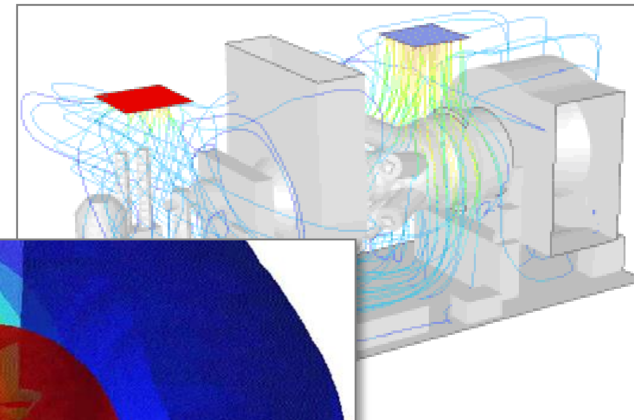
- CFD is widely used for technical safety applications:



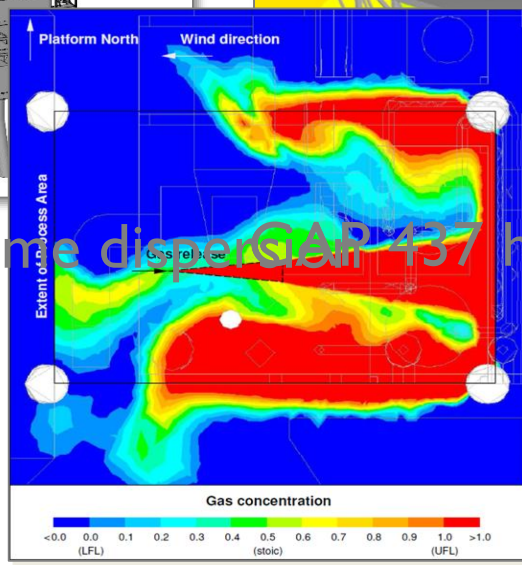
Exhaust plume dispersion



CAP 437 helideck assessment



ISO 15138 assessment of ventilation efficiency



Gas dispersion in the event of a loss of containment

Explosions

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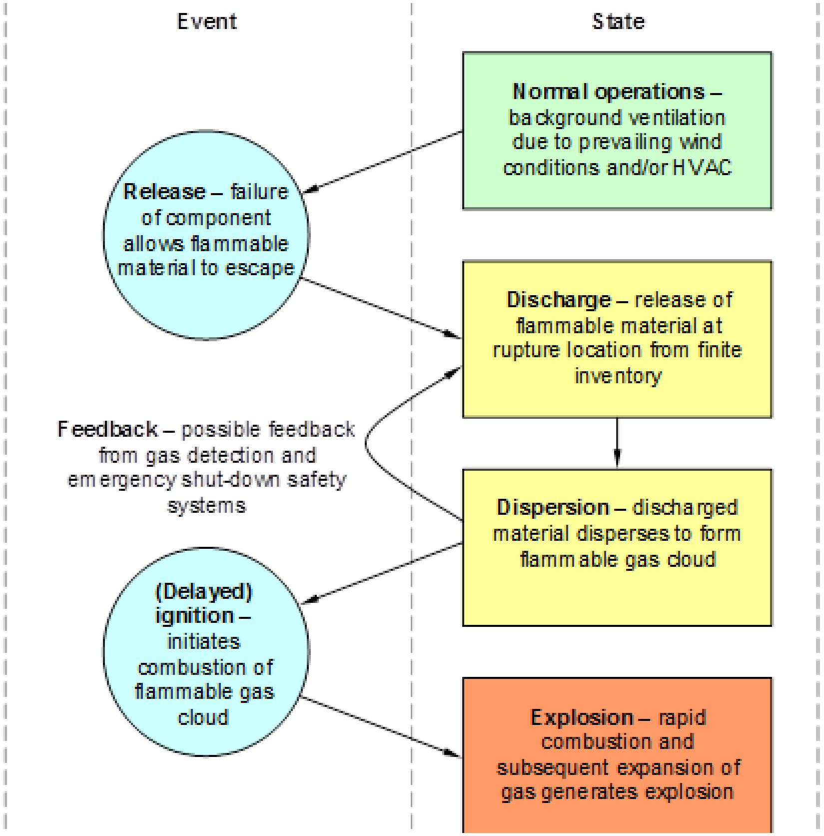
Probabilistic explosion assessment

- CFD can be used to simulate a well defined explosion event – this is deterministic
- How do you define which:
  - Flammable cloud
  - Ignition point
- How should the flammable cloud be defined:
  - Geometry (typically rectangular)
  - Composition (typically stoichiometric composition).

Probabilistic explosion assessment

Simulate the sequence of events that lead up to any potential explosion event –

- background ventilation during normal operations
- dispersion following a release
- explosion following ignition.



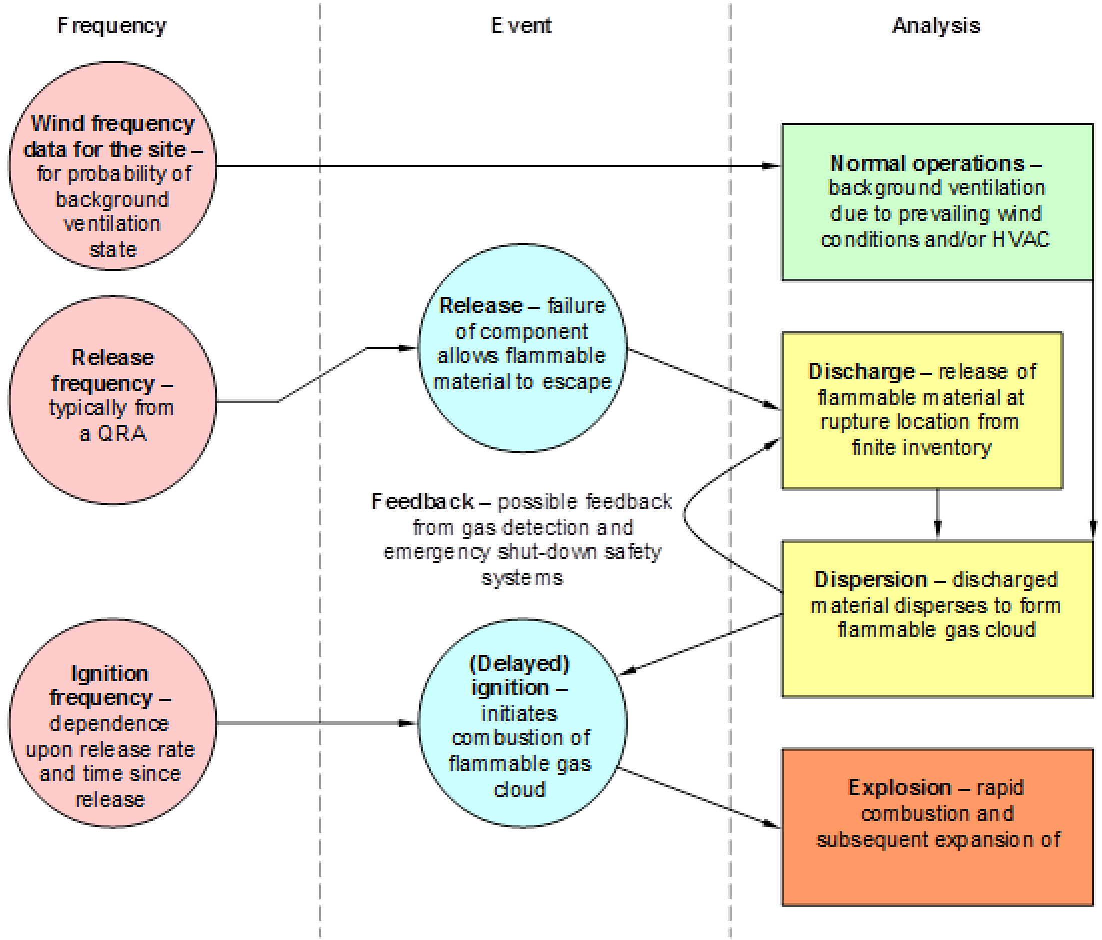
Deterministic sequence!

Probabilistic explosion assessment

- Determining a suitable basis for the design explosion load for a structure can be challenging
- Considering a worst-case, large release event will typically lead to explosion loads that are well in excess of what can be realistically designed for
- A more pragmatic option is to adopt a probabilistic approach to construct explosion load exceedance curves describing the probability of a particular load occurring
- This is the recommended procedure outlined in Annex F of *Risk and emergency preparedness assessment*, **NORSOK Standard Z-013** (Edition 3 is dated October 2010).

Probabilistic explosion assessment

By simulating a large dataset of scenarios, and with an understanding the frequencies of occurrence at each stage, it is possible to construct exceedance curves for the explosion load at any point of interest.



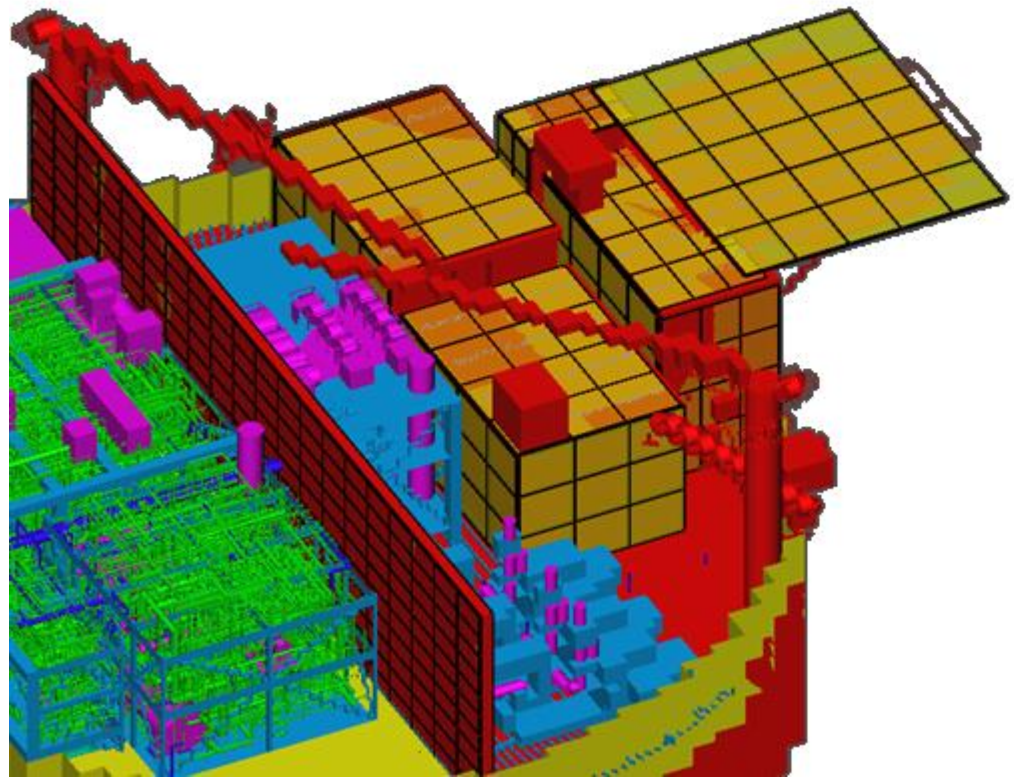
Probabilistic explosion assessment

- A typical probabilistic explosion assessment may comprise
  - Twelve ventilation CFD simulations
  - Several hundred transient dispersion CFD simulations
  - Several hundred explosion CFD simulations
- Each explosion CFD model may include several thousand monitor points or (2D) panels of interest which the instantaneous explosion overpressure is predicted
  - The pressure trace can be approximated using a triangulation defined by eight parameters, including the maximum predicted overpressure and underpressure, and the positive and negative impulse.

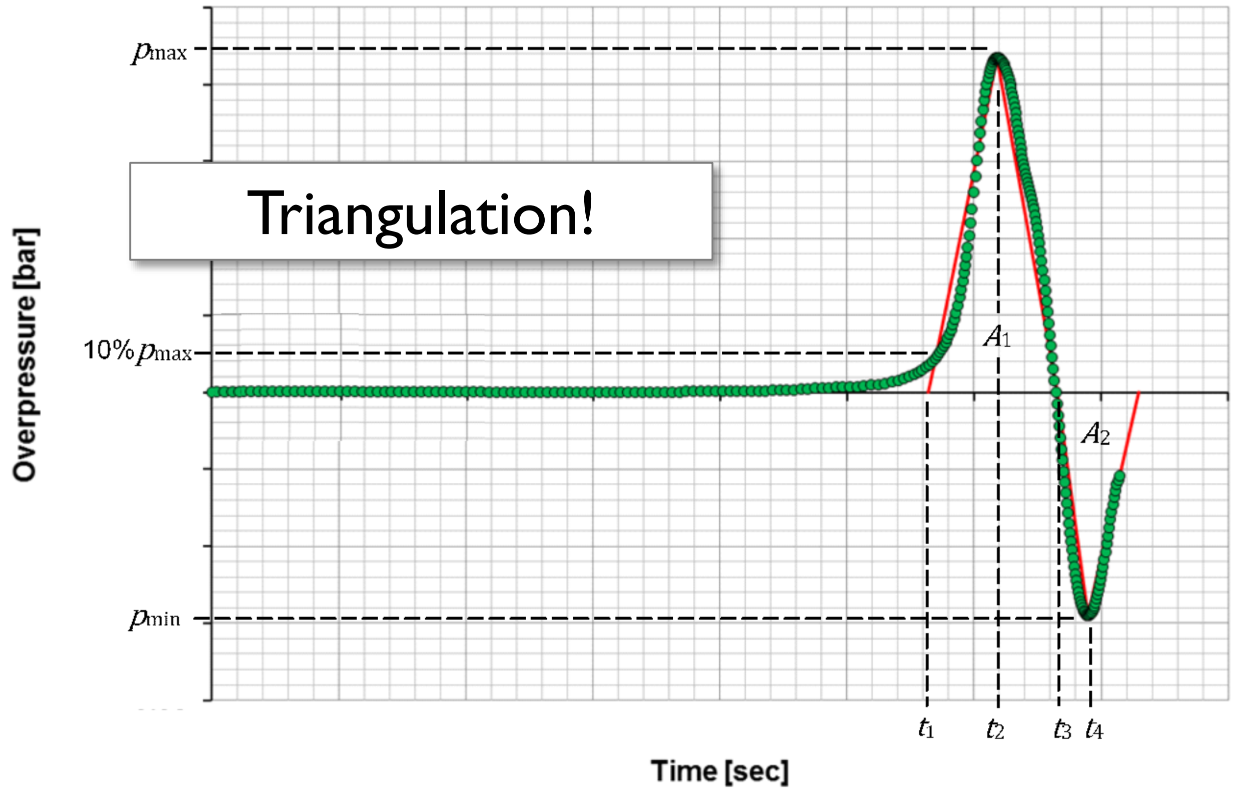
Probabilistic explosion assessment

Example of an FPSO showing arrays of 2D monitor panels across the targets of interest:

- Blast wall
- LQ/TR
- Helideck.

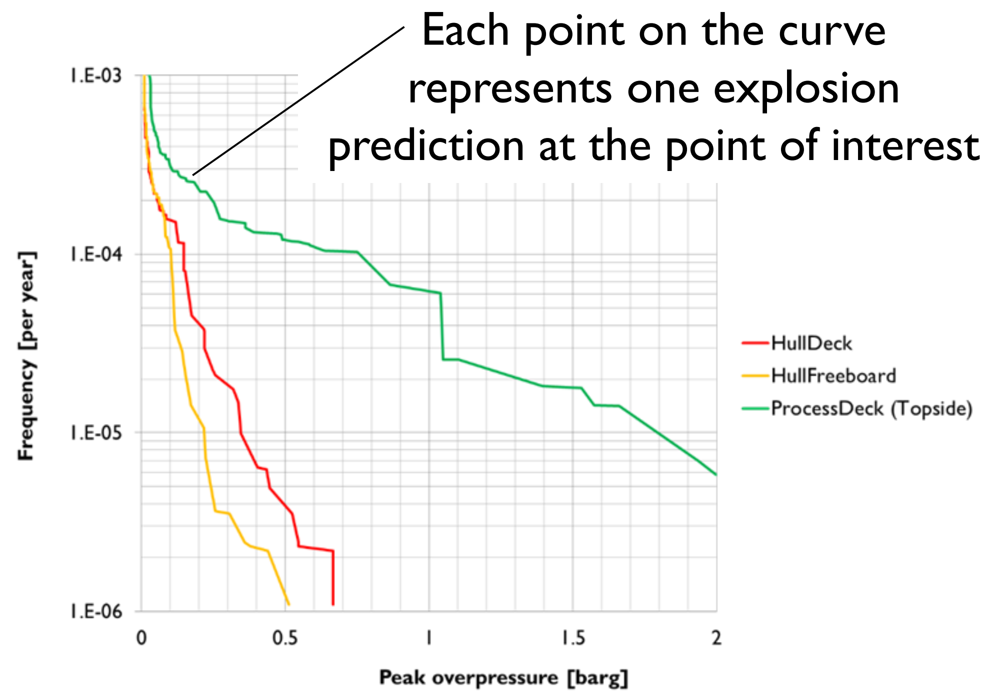


Probabilistic explosion assessment



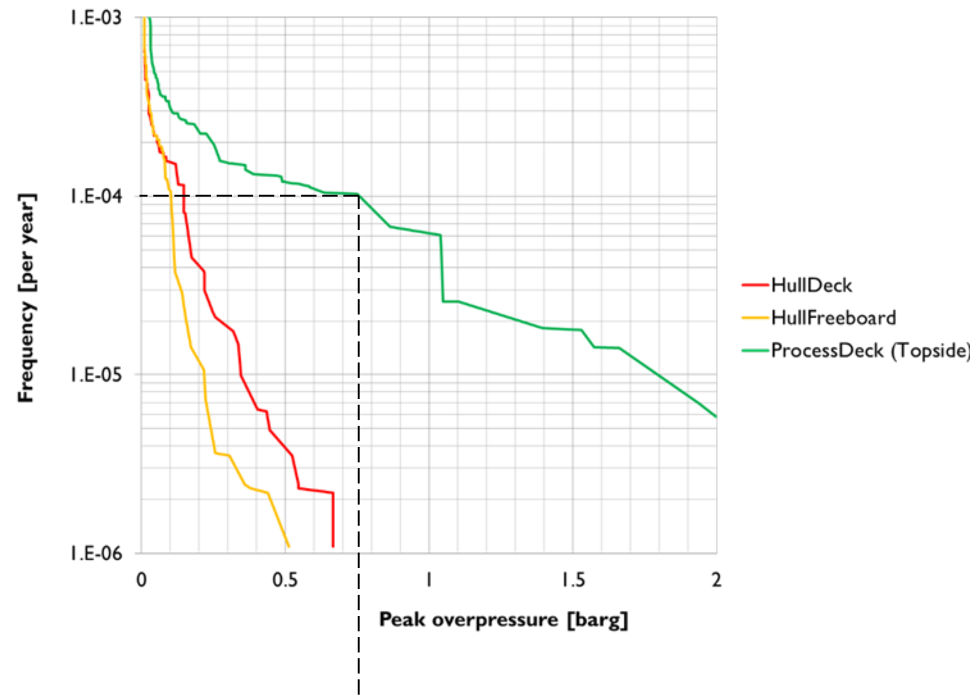
Probabilistic explosion assessment

The figure to the right shows a typical set of exceedance curves for peak overpressure, although similar curves can be constructed for underpressure and positive/negative impulses.



Probabilistic explosion assessment

Typically an allowable frequency of occurrence is taken to be 10^{-4}/yr, and the exceedance curves are used to determine the corresponding explosion loads.



Design explosion load of 0.75 barg for the process deck

Nothing new so far!

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Improving the integration of analysis data

- There is a huge amount of predictive data generated during the course of a probabilistic explosion assessment that could be extremely useful to the structural engineer
- This is often not utilised because the probabilistic explosion assessment and the structural design are typically undertaken by different parties and the sharing of information has not been easy
- The interface between the parties generally comprises the transfer of a single DAL for each target of interest, the 10^{-4}/yr DAL, comprising the 10^{-4}/yr peak overpressure and an associated measure of the duration of the 10^{-4}/yr blast.

Improving the integration of analysis data

- The probabilistic methodology outlined in NORSOK Z-013 is not new, and many consultants have, over the last decade, developed their own in-house tools to perform this analysis
- The precise details of each in-house tool tend to be kept secret, perhaps because of the intellectual investment associated with the development of the tool
- The NORSOK Z-013 methodology, however, is open to interpretation, which means that there could be inconsistent approaches between different consultants, which is not good for our industry.

Improving the integration of analysis data

- There is currently no software tool available for use that is designed specifically for undertaking the probabilistic analysis
- Such a tool would provide a single reliable methodology for the industry and would minimise any inconsistencies which may currently exist
- Abercus has developed **EXCGEN**, a software tool for undertaking probabilistic assessments.

Improving the integration of analysis data

- Abercus has developed **EXCGEN** with the associated key benefits to the design team that are not yet commonly available:
  - Sharing and associated democratisation of analysis data
  - 3D risk assessment
  - Probabilistic structural response.
- Enabling easier data sharing can enable improved interaction between the structural engineer and explosion analyst
- This can allow, for example, the sensitivity of explosion loads with respect to the underlying assumptions to be explored
- Deeper understanding of explosion events should lead to better, safer design.

Improving the integration of analysis data

- There are additional benefits for similar types of study, since the underlying set of CFD simulations can be used to predict:
  - Ventilation efficiencies in accordance with ISO 15138 (both global and local ventilation efficiency)
  - Probabilistic assessment of flammable accumulation, which can feed into a gas detector layout study.

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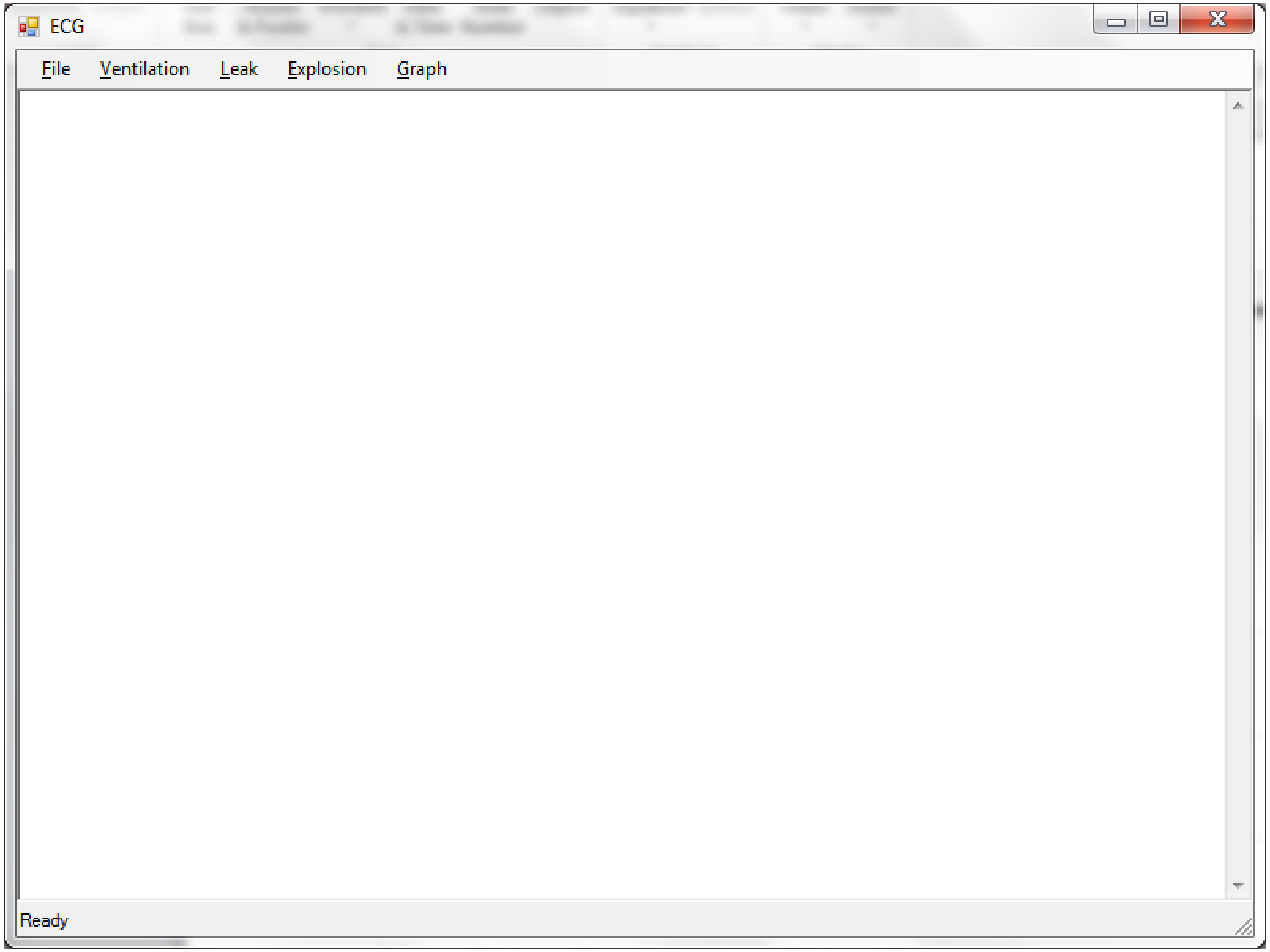
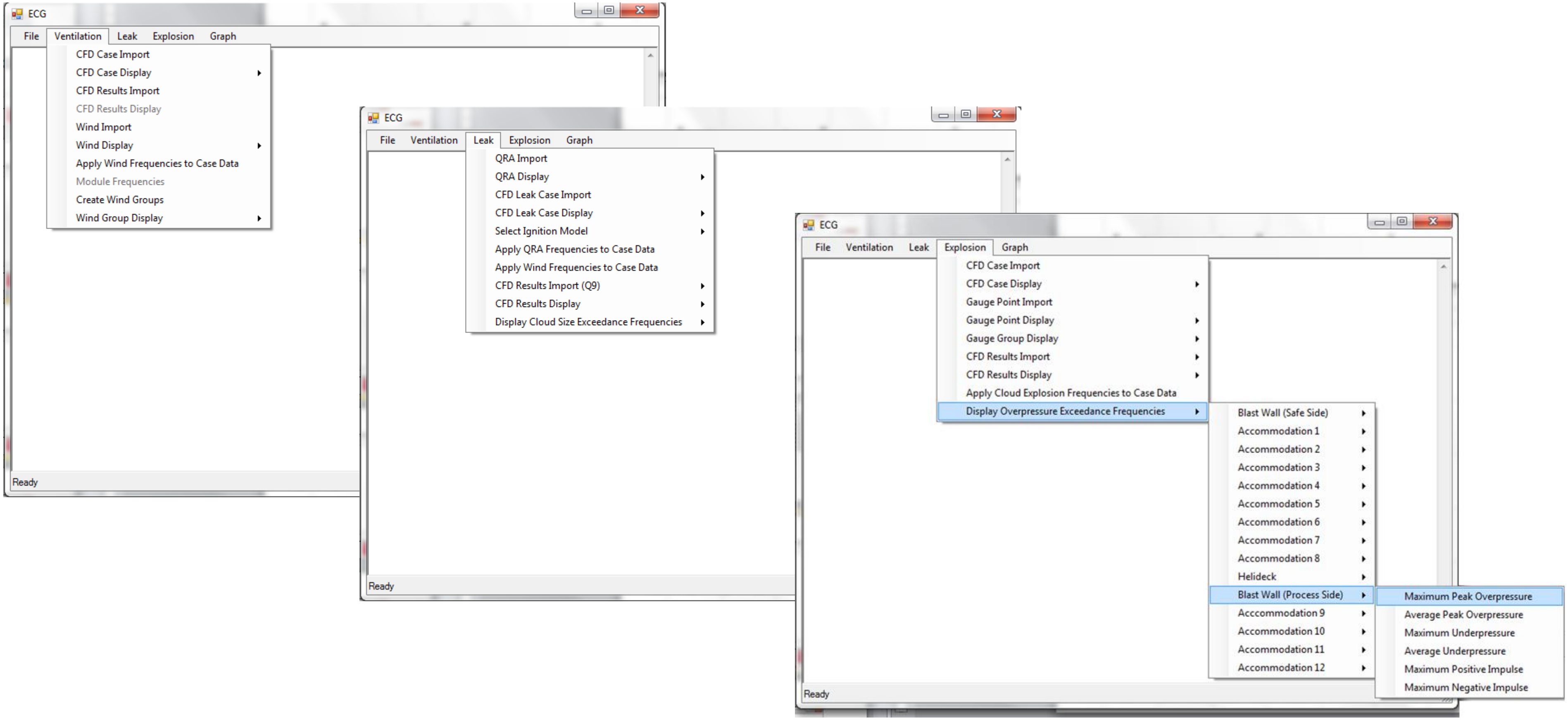
EXCGEN



EXCGEN


ECG
File
Ventilation
Leak
Explosion
Graph
CFD Case Import
CFD Case Display
CFD Results Import
CFD Results Display
Wind Import
Wind Display
Apply Wind Frequencies to Case Data
Module Frequencies
Create Wind Groups
Wind Group Display
Ready
QRA Import
QRA Display
CFD Leak Case Import
CFD Leak Case Display
Select Ignition Model
Apply QRA Frequencies to Case Data
Apply Wind Frequencies to Case Data
CFD Results Import (Q9)
CFD Results Display
Display Cloud Size Exceedance Frequencies
Gauge Point Import
Gauge Point Display
Gauge Group Display
Apply Cloud Explosion Frequencies to Case Data
Display Overpressure Exceedance Frequencies
Blast Wall (Safe Side)
Accommodation 1
Accommodation 2
Accommodation 3
Accommodation 4
Accommodation 5
Accommodation 6
Accommodation 7
Accommodation 8
Helideck
Blast Wall (Process Side)
Acccommodation 9
Accommodation 10
Accommodation 11
Accommodation 12
Maximum Peak Overpressure
Average Peak Overpressure
Maximum Underpressure
Average Underpressure
Maximum Positive Impulse
Maximum Negative Impulse

EXCGEN

- **EXCGEN** is based upon a logical, documented methodology
- The probabilistic assessment is based upon data extracted from the underlying CFD simulation files, stored in text format which can be shared without excessive file storage requirements
- The underlying file system is human-readable so that it can be easily audited
- It allows us to easily explore and interrogate specific event-chains in the ventilation-dispersion-explosion sequence of events.

EXCGEN

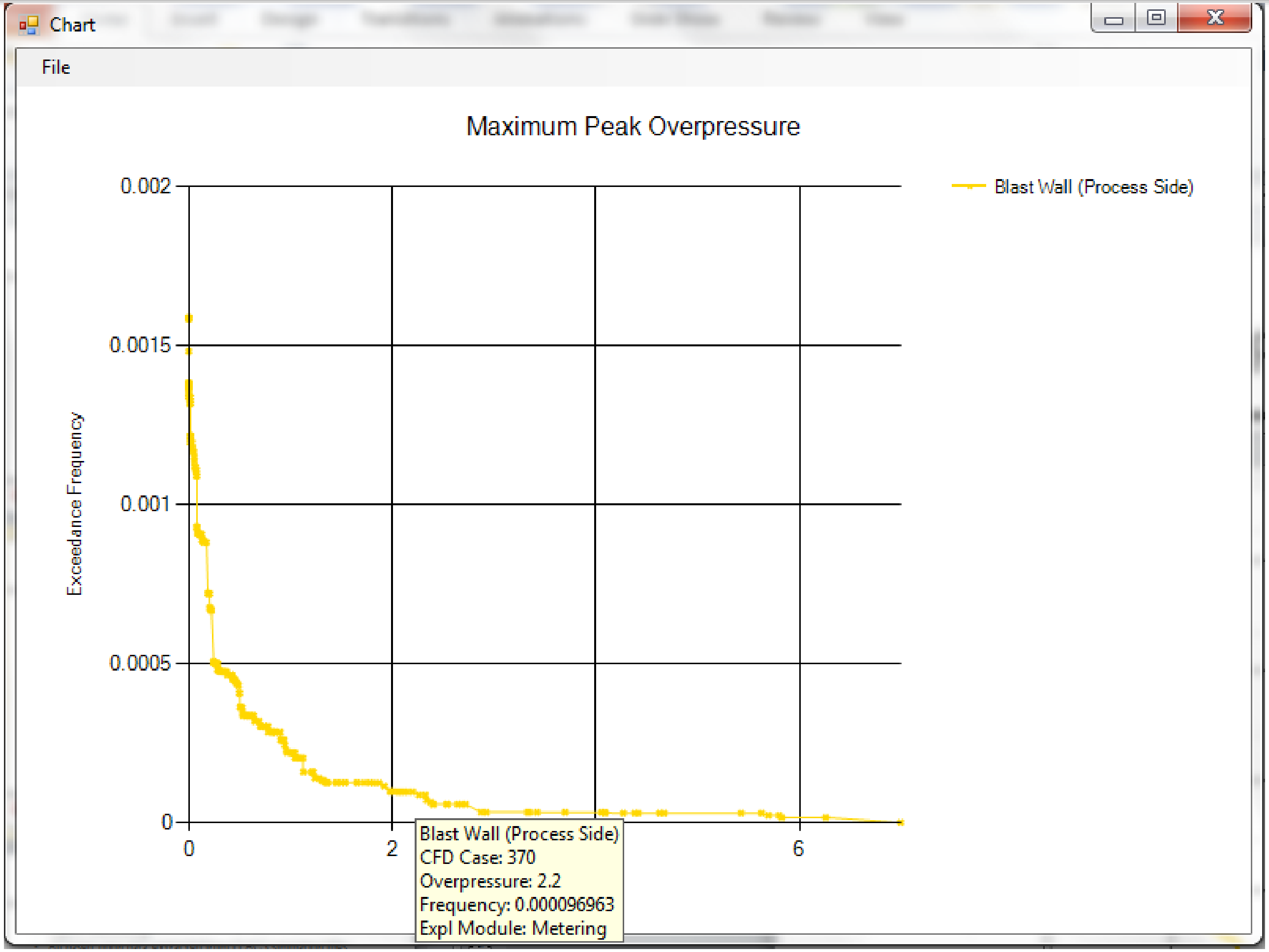


Chart
File
Maximum Peak Overpressure
Blast Wall (Process Side)
Exceedance Frequency
0.002
0.0015
0.001
0.0005
0
0
2
6
Blast Wall (Process Side)
CFD Case: 370
Overpressure: 2.2
Frequency: 0.000096963
Expl Module: Metering

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Sharing/democratisation of analysis data

- **EXCGEN**'s underlying file system is generated from, but separate to, the underlying CFD files, which allows the information to be easily shared
- Sensitivities to (some of) the probabilistic assumptions can be considered on-the-fly, in the company of the design team
  - Ignition methodology
  - Underlying wind conditions
  - Flammable volume methodology
  - Release frequencies from the QRA
- Typically these sensitivities may not be explored.

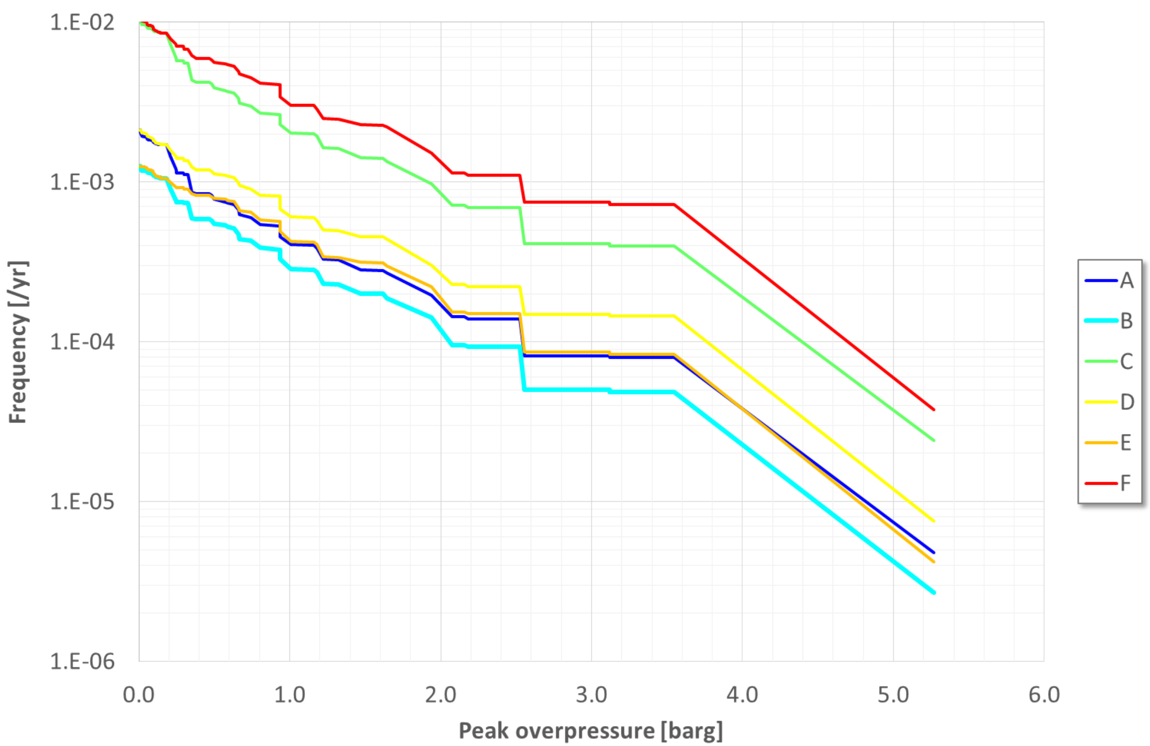
Sharing/democratisation of analysis data

Ignition methodology	Probability of ignition	Probability of explosion given ignition	Time dependence
A	UKOOA 25	Fixed at 20%	UKOOA
B	UKOOA 25	Cox, Lees and Ang	UKOOA
C	UKOOA 25	Ignored	UKOOA
D	UKOOA 25	Fixed at 20%	Ignored
E	UKOOA 25	Cox, Lees and Ang	Ignored
F	UKOOA 25	Ignored	Ignored

Sensitivity cases relating to ignition methodology

Sharing/democratisation of analysis data

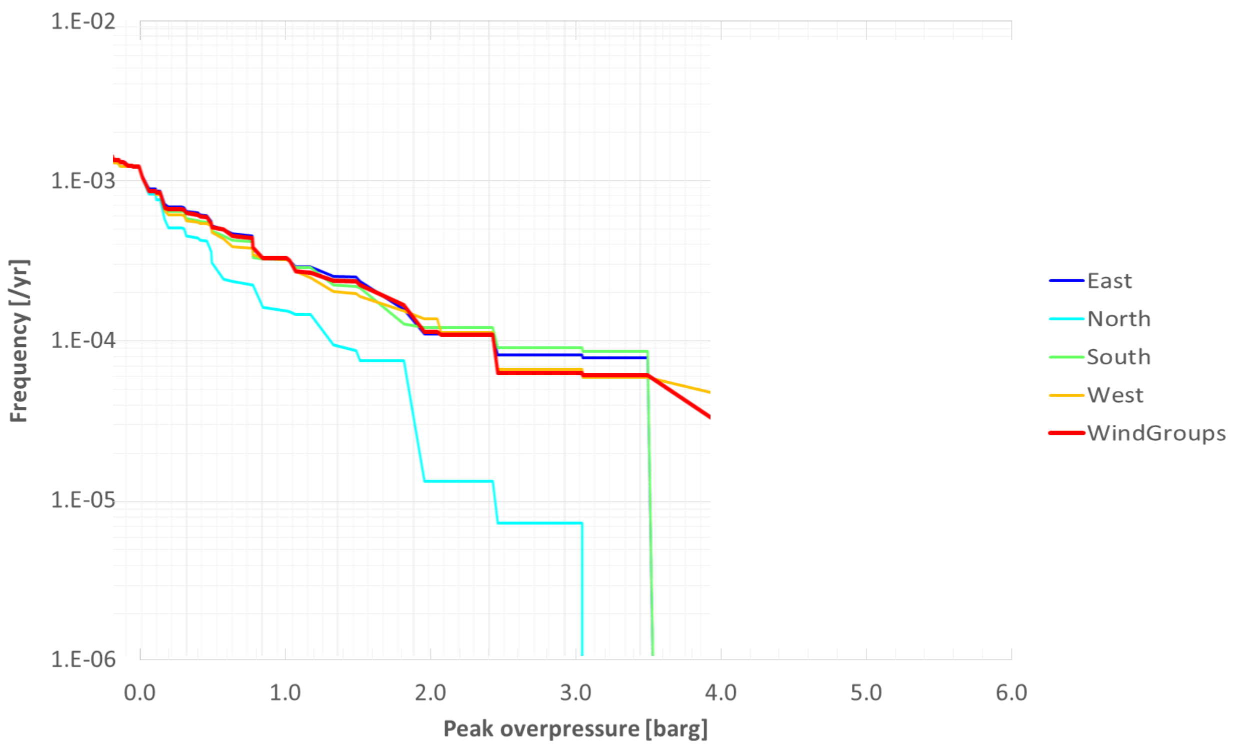
Sensitivity cases relating to ignition methodology



Exceedance curves for peak overpressure

Sharing/democratisation of analysis data

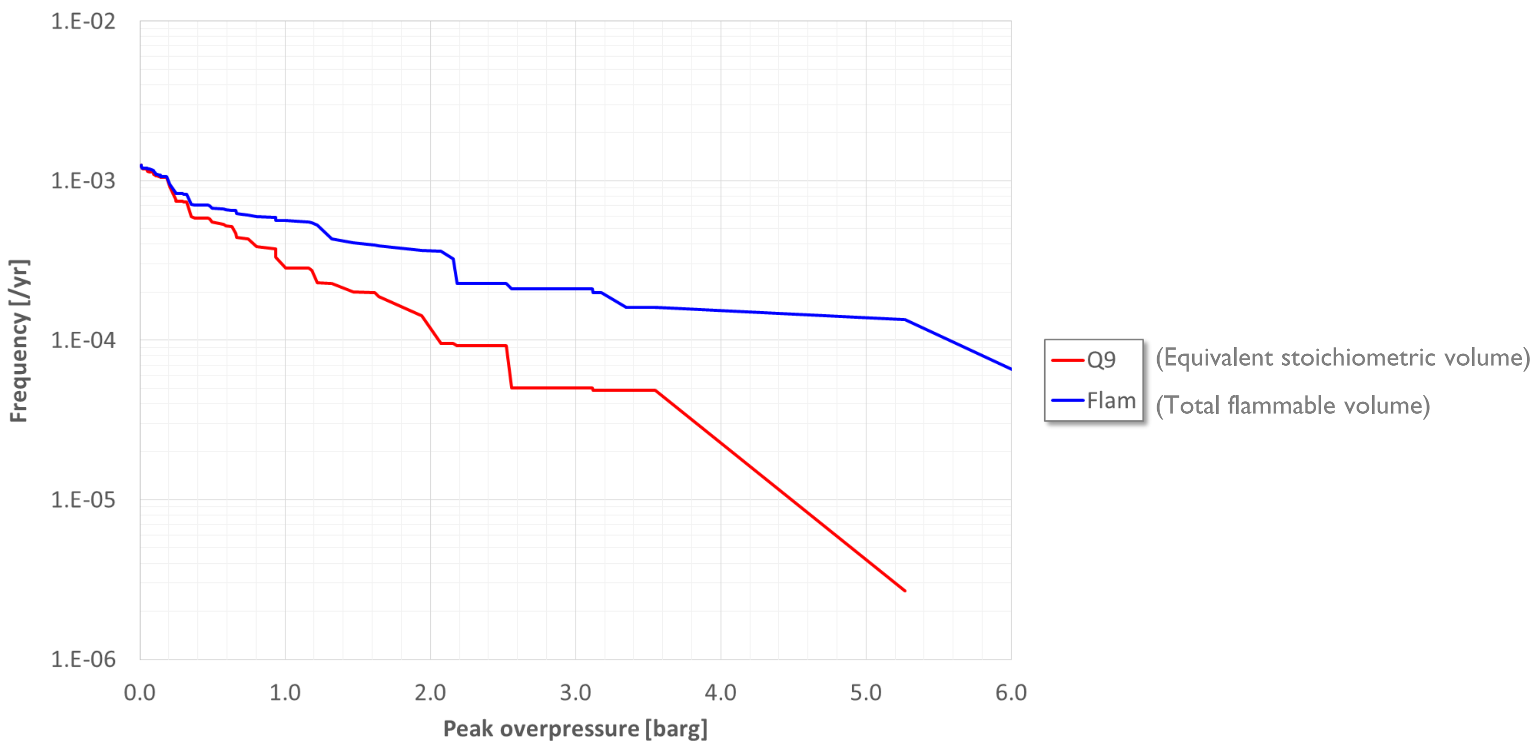
Sensitivity cases relating to underlying ventilation pattern/wind direction



Exceedance curves for peak overpressure

Sharing/democratisation of analysis data

Sensitivity cases relating to flammable volume methodology



Exceedance curves for peak overpressure

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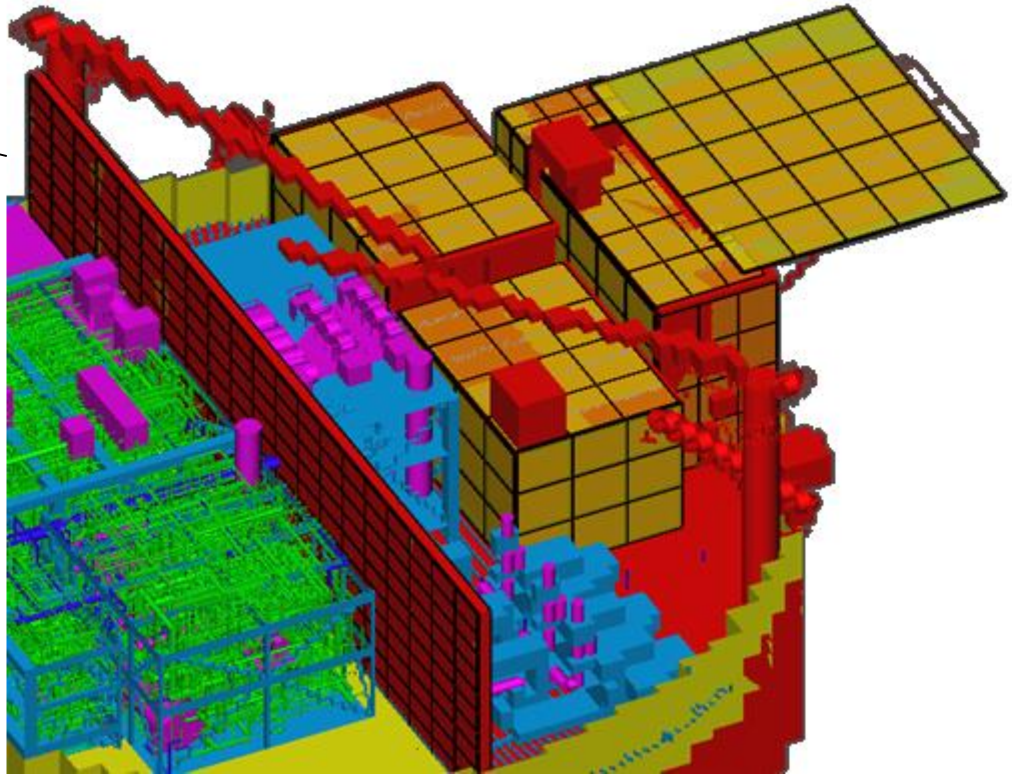
3D risk assessment

- Perhaps because it is not straightforward to share information between different parties, the design explosion loads are typically extracted from the exceedance curve for each structural target and provided to the structural engineer as a single design load for each target
- The explosion loads, particularly for large targets such as blast walls may vary across the target, so providing a single value for the design load may be overly conservative.

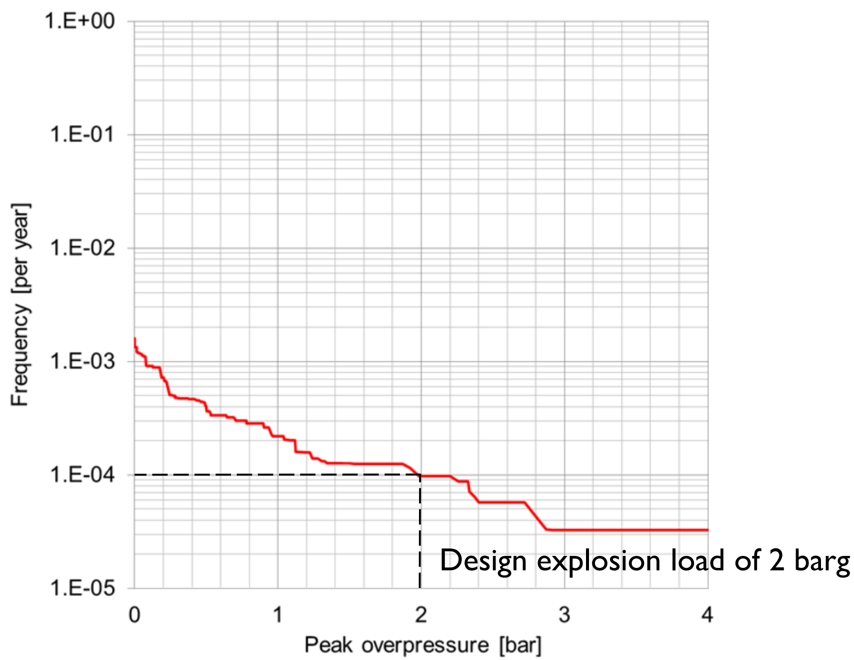
3D risk assessment

Blast wall, represented by a discretised array of monitor panels within the FLACS model



3D risk assessment

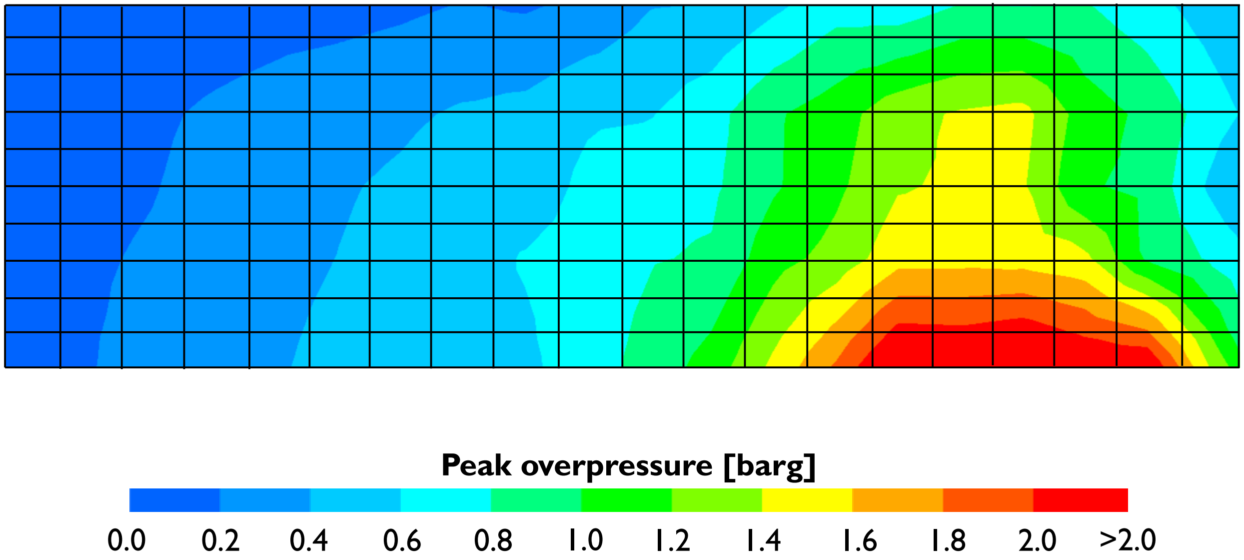
For this example, the 10^{-4}/yr peak overpressure for the blast wall is 2 barg.



3D risk assessment

The design explosion load retrieved from the exceedance curve (2 barg) is localised – the 10^{-4}/yr overpressure for the majority of the blast wall is significantly less than 2 barg.

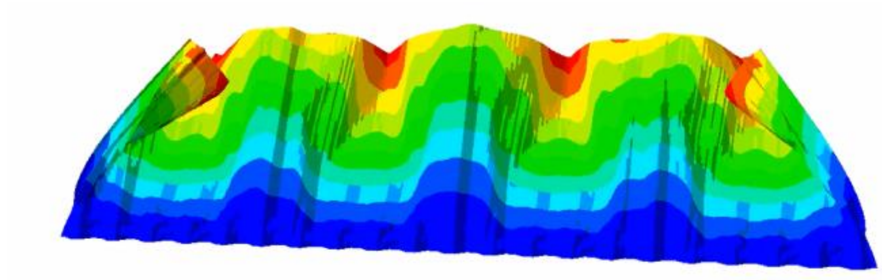
Contour plot of 10^{-4}/yr peak overpressure



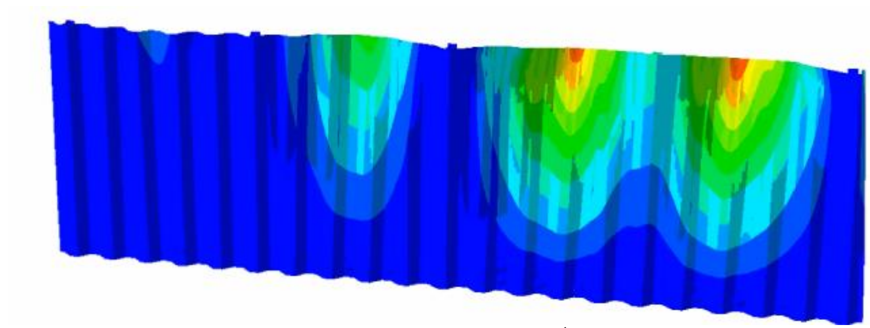
3D risk assessment

This can have a significant impact upon the structural response of the blast wall under DAL loading.

Contour plot of normalised deflection



2 bar overpressure uniformly applied



Contours of overpressure for 10^{-4}/yr pseudo-event

Normalised deflection

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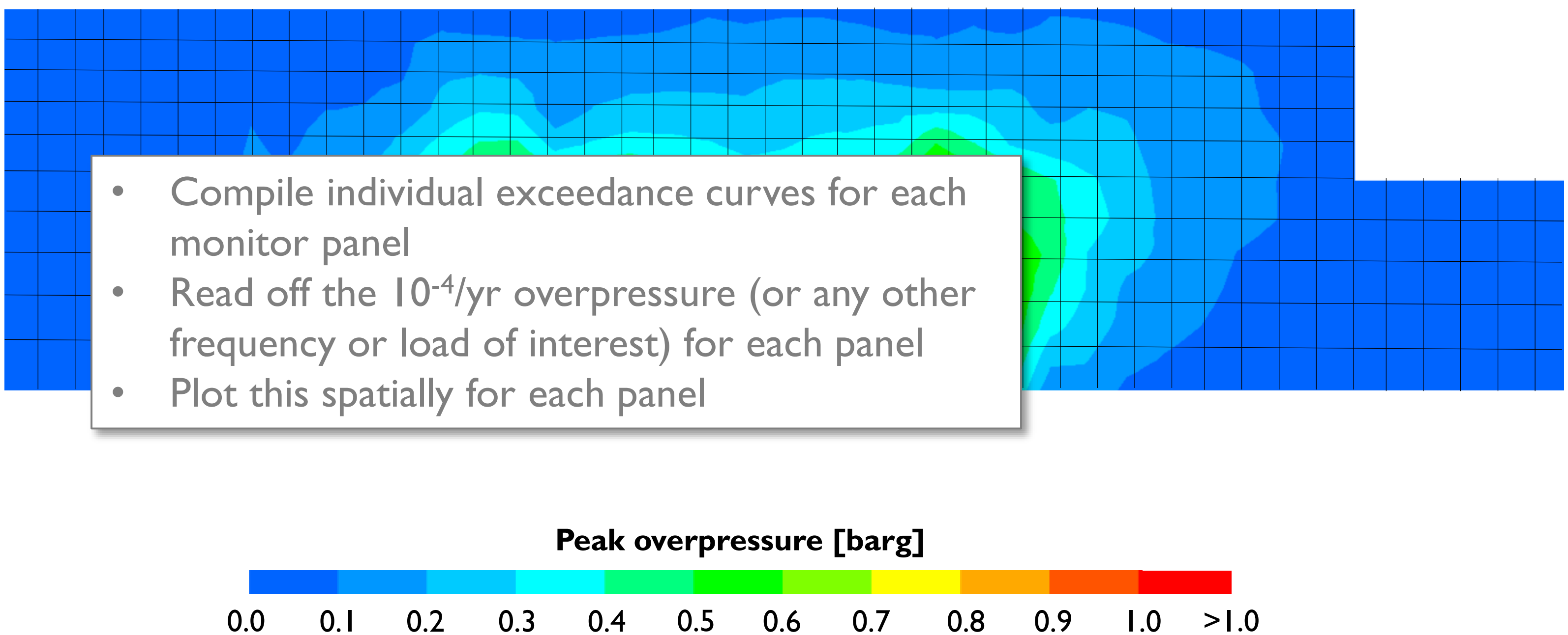
Selection of representative 10^{-4}/yr events

- **EXCGEN** can link to FEA codes to directly apply 3D spatially varying explosion loads on an FEA model
- What explosion load should be applied?
- Is it even possible to satisfactorily define a representative 10^{-4}/yr event?

Selection of representative 10^{-4}/yr events

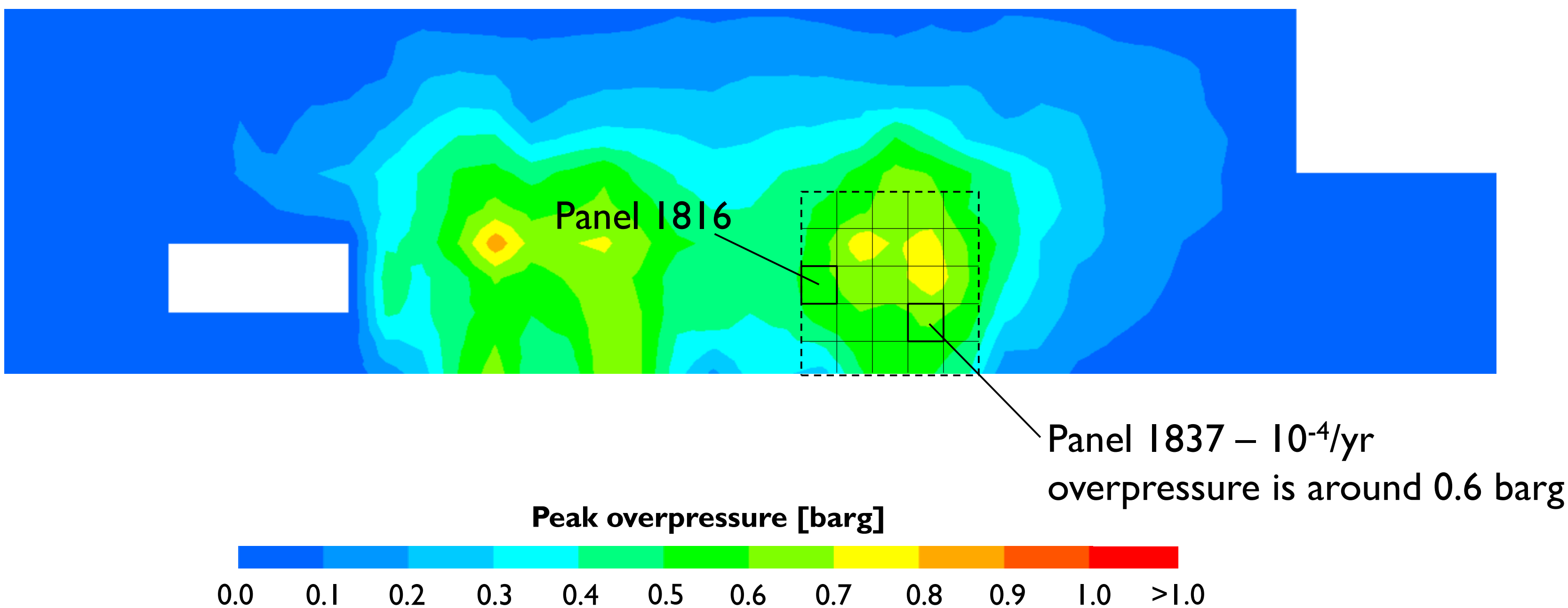
Contour plot of 10^{-4}/yr peak overpressure



- Compile individual exceedance curves for each monitor panel
- Read off the 10^{-4}/yr overpressure (or any other frequency or load of interest) for each panel
- Plot this spatially for each panel

Selection of representative 10^{-4}/yr events

Contour plot of 10^{-4}/yr peak overpressure



Selection of representative 10^{-4}/yr events

- At panel 1837, the 10^{-4}/yr peak overpressure is around 0.6 barg

Selection of representative 10^{-4}/yr events

Event indices for the 10^{-4}/yr event at each panel

171	172	32	36	114	169	168	113	34	113	121	121	121	121	148	122	166	154	145	79	153	105	70	114	158	177	174	144	33	33	144	144	61	164	61						
122	32	114	104	169	168	121	168	113	168	168	169	171	169	112	122	155	159	145	104	59	105	59	59	172	151	60	70	33	33	61	144	144	159	35						
122	122	32	169	114	168	164	121	113	113	33	169	171	31	164	80	170	170	112	154	59	152	158	81	158	168	159	70	35	61	144	144	144	61	61						
168	114	114	168	168	104	81	81	168	164	36	169	32	169	112	122	61	161	160	112	166	71	172	158	151	159	159	144	144	144	168	168	61	61	36						
168	114	34	34	121	121	121	113	114	32	35	114	114	33	32	169	170	123	123	104	105	144	153	35	144	35	144	71	150	150	144	168	168	168	61						
164	171	171	34	113	81	113	164	168	34	114	33	30	169	36	34	111	111	111	167	154	154	154	34	158	164	159	36	71	150	150	168	168	168	168	168	168	150	165	81	129
104	164	122	171												110	110	176	162	104	144	172	61	157	61	164	71	36	35	164	34	144	81	81	168	168	70	150	165	69	150
104	169	164	113												170	176	110	123	34	157	81	71	31	145	147	31	161	36	160	160	144	144	60	70	70	81	60	165	69	150
81	61	122	121												170	31	164	161	104	166	173	61	155	145	162	33	161	145	34	35	150	168	160	81	70	60	60	60	80	151
29	130	61	19												169	36	177	34	177	61	61	34	31	145	31	36	166	35	162	71	150	144	70	60	81	60	165	124	81	131

154	34	158	164	159
61	157	61	164	71
71	31	145	147	31
61	155	145	162	33
34	31	145	31	36

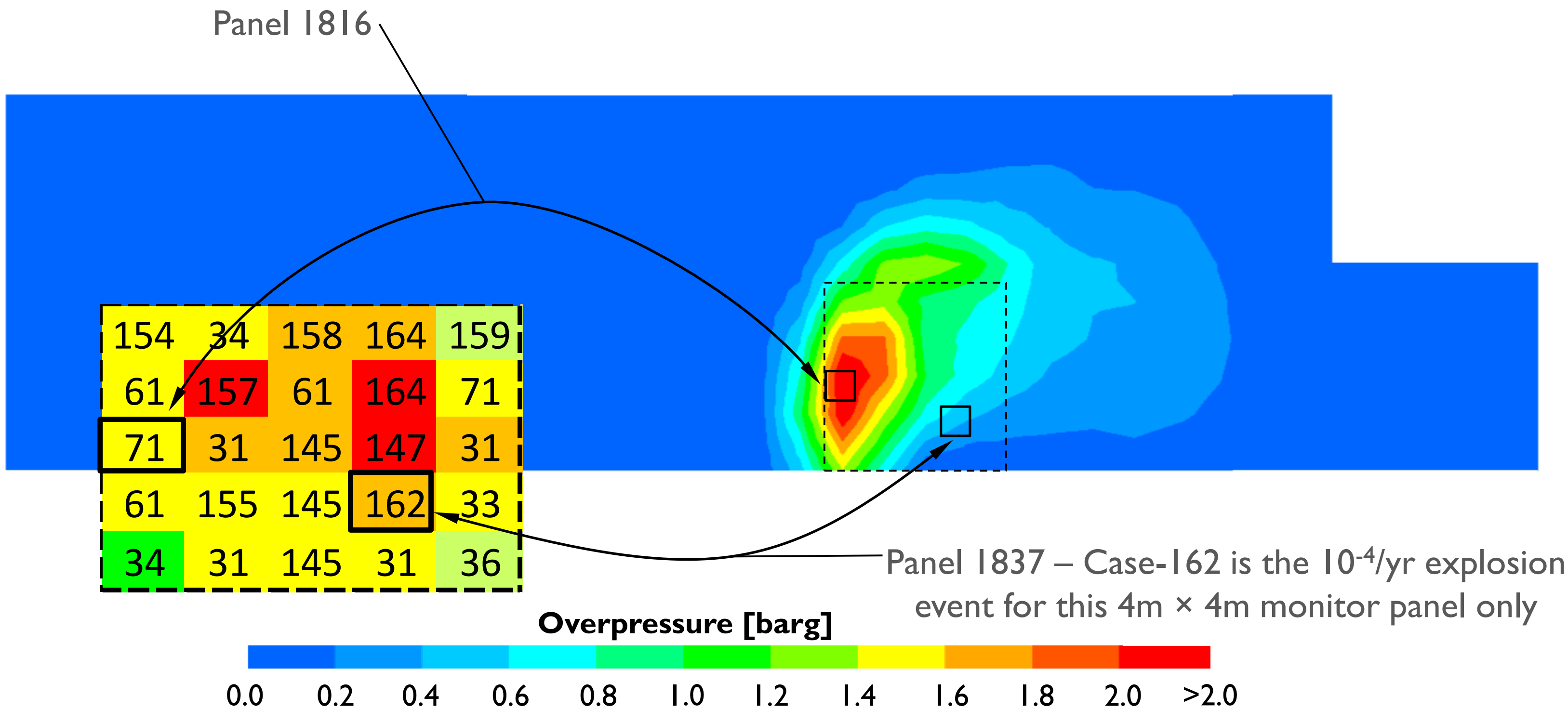
At panel 1837, the explosion event corresponding to the 10^{-4}/yr peak overpressure is event 162

Selection of representative 10^{-4}/yr events

- At panel 1837, the 10^{-4}/yr peak overpressure is around 0.6 barg
- The explosion event corresponding to this 10^{-4}/yr peak overpressure is event 162

Selection of representative 10^{-4}/yr events

Maximum peak overpressure for explosion event 162

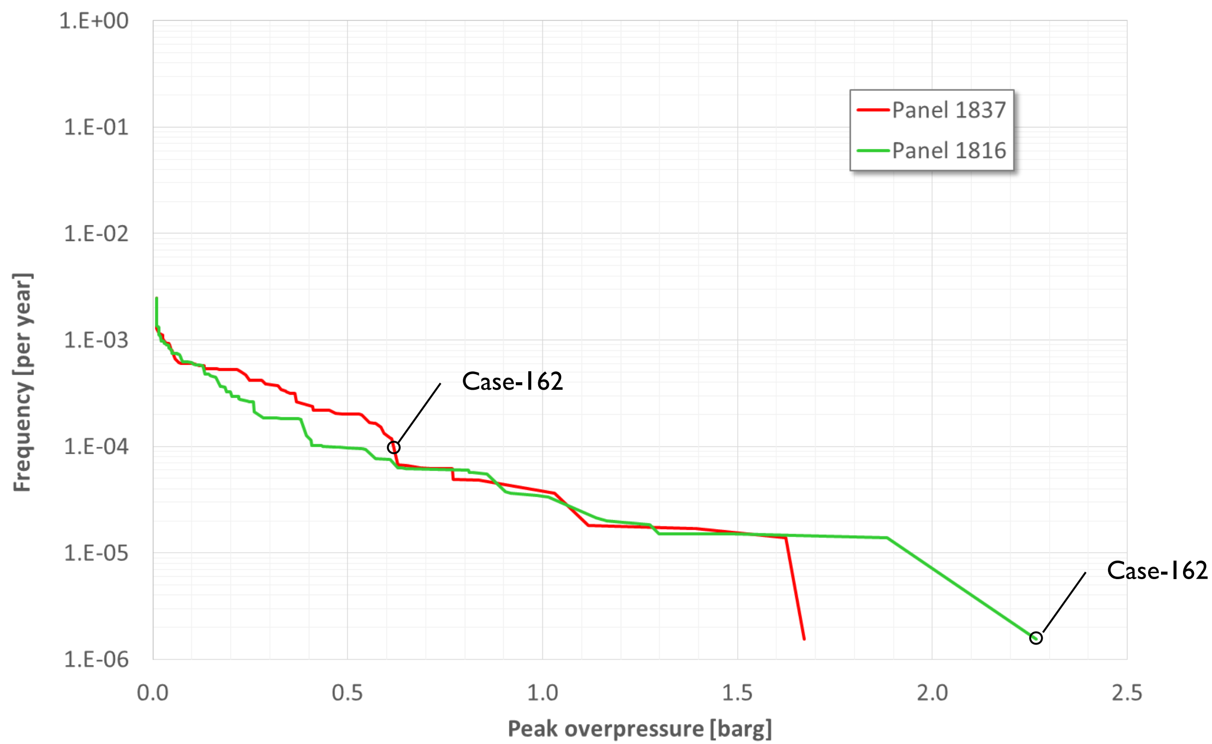


Maximum instantaneous overpressure (averaging area 4m × 4m)

Selection of representative 10^{-4}/yr events

- At panel 1837, the 10^{-4}/yr peak overpressure is around 0.6 barg
- The explosion event corresponding to this 10^{-4}/yr peak overpressure is event 162
- The peak overpressure for event 162 is over 2 barg, which is significantly higher than the 10^{-4}/yr overpressure, but it occurs in a different location (at panel 1816)
- From the exceedance curves, event 162 represents a lower frequency of occurrence at panel 1816 and, therefore, this higher overpressure does not contribute to the 10^{-4}/yr overpressure reported on the contour plot.

Selection of representative 10^{-4}/yr events

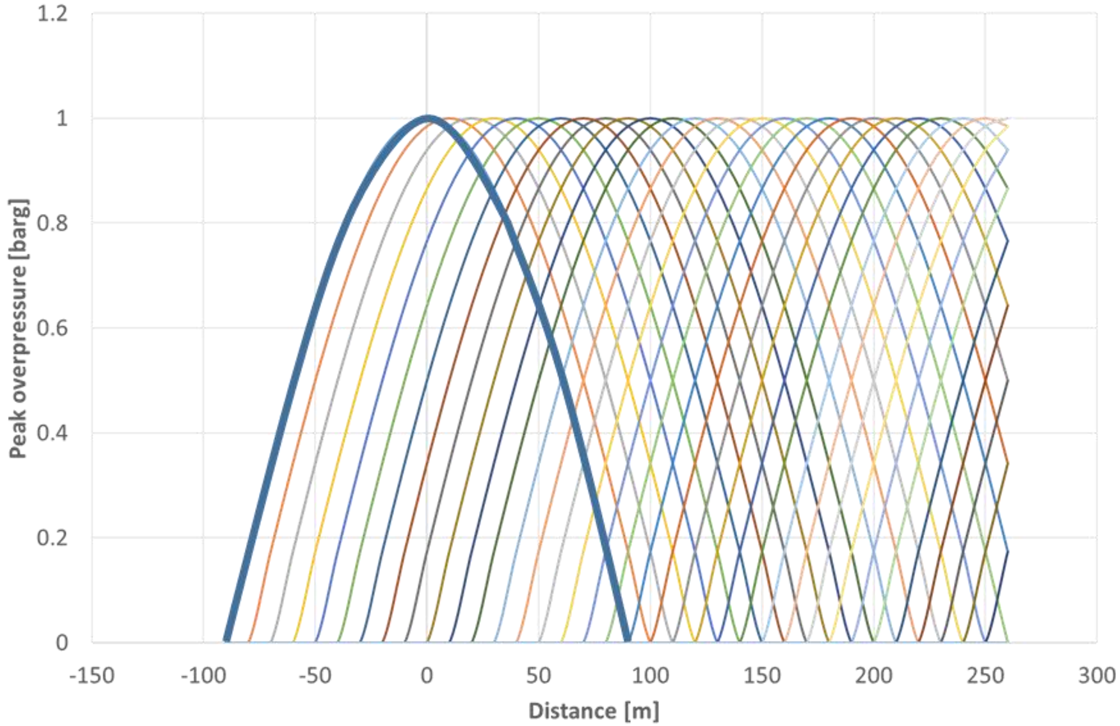


Exceedance curves for panels 1837 and 1816

Selection of representative 10^{-4}/yr events

- Imagine that we have simulated a series of identical blast events, such that the blast dynamics for each event are similar, but with the clouds displaced at 10m intervals
- Imagine that the variation of the peak overpressure with distance along a deck for the first event which has a **peak overpressure of 1 barg**
- If we then plot the peak overpressure for all of the blast events on the same plot, we have the same shaped curve but it is repeated at intervals of 10m.

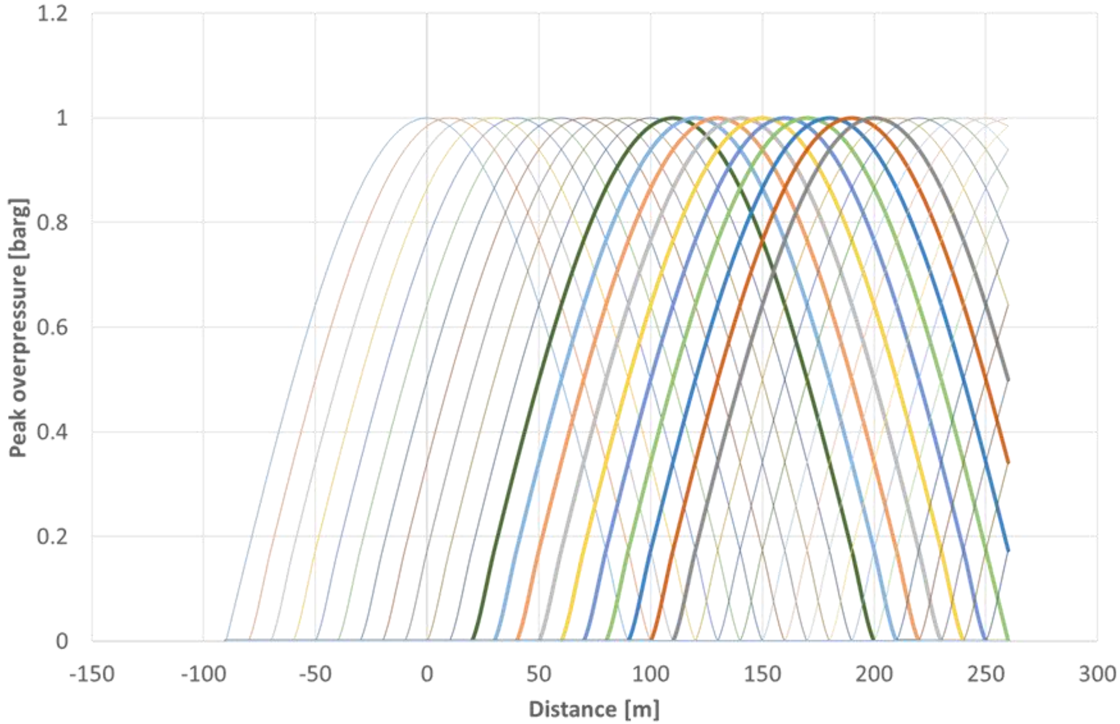
Selection of representative 10^{-4}/yr events



Selection of representative 10^{-4}/yr events

- Imagine that each blast event individually has a probability of occurrence of 10^{-5}/yr
- This means that to find the 10^{-4}/yr overpressure at any point along the deck there needs to be 10 of the curves which, at that point, has a higher local peak overpressure
- To illustrate this 10 of the curves are identified in bold in the upper part of the figure.

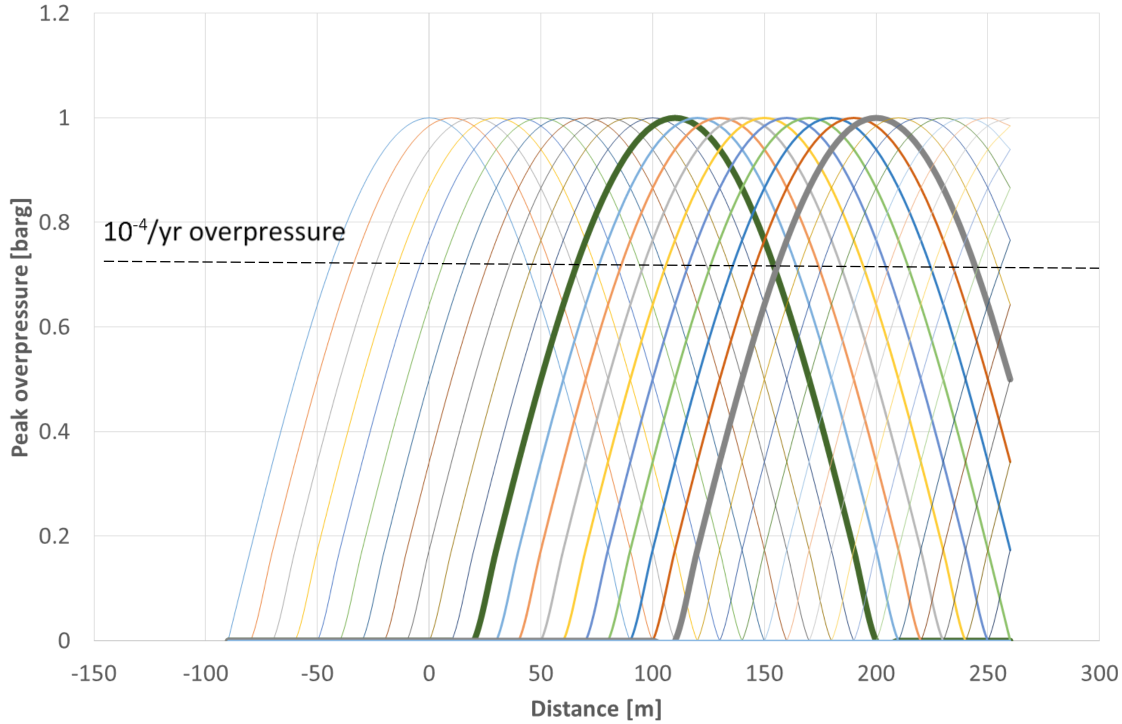
Selection of representative 10^{-4}/yr events



Selection of representative 10^{-4}/yr events

- If we then consider the 150m location, the **10^{-4}/yr peak overpressure is 0.7 barg** – at this point, 10 of the curves have a peak overpressure in excess of 0.7 barg – with the probabilistic approach we can ignore the higher overpressure events at this location, hence the lower 10^{-4}/yr overpressure when compared to the peak value for each of the curves individually
- In this idealised example, the events represented by the dark green and dark grey curves in the figure below are the representative 10^{-4}/yr events, each of which has a **peak overpressure of 1 barg.**

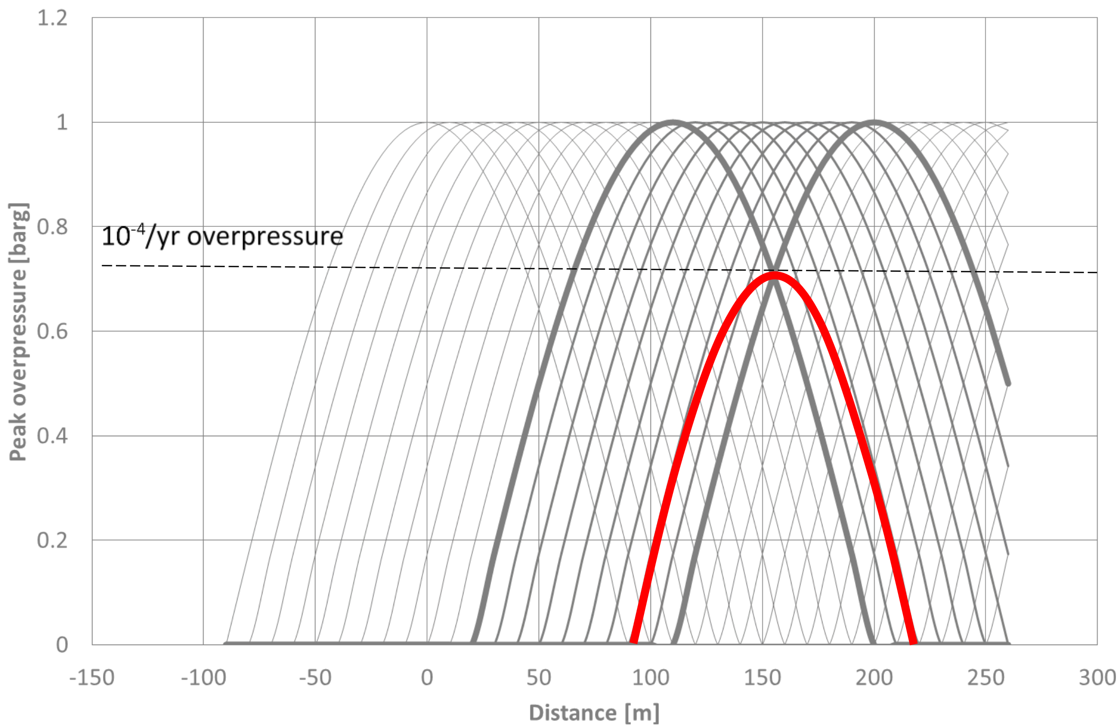
Selection of representative 10^{-4}/yr events



Selection of representative 10^{-4}/yr events

- When selecting representative events it is important not to simply select an event which has a peak overpressure comparable to the local 10^{-4}/yr overpressure – doing so would be equivalent to selecting the red curve, which is a lesser event than either of the 10^{-4}/yr events we identified previously, represented by the grey bold curves.

Selection of representative 10^{-4}/yr events



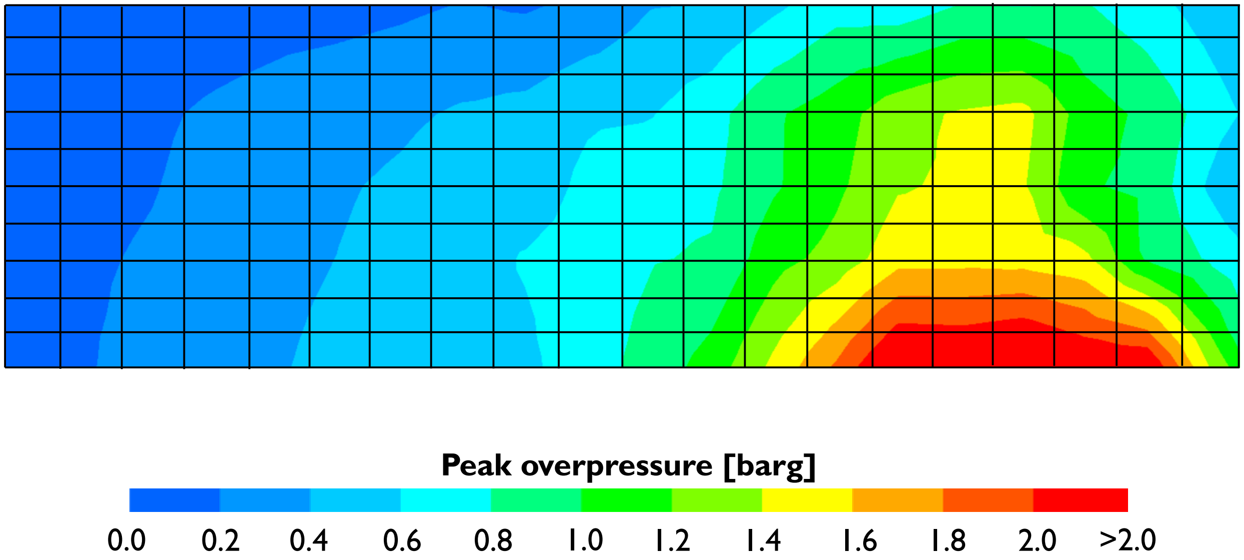
Selection of representative 10^{-4}/yr events

- It is generally not necessarily possible to identify any single individual event from the underlying simulated explosion events as a representative 10^{-4}/yr event
- The contour plots of 10^{-4}/yr overpressure receive contributions from a wide range of explosion events
- Is it possible to construct a 10^{-4}/yr pseudo-event?

Selection of representative 10^{-4}/yr events

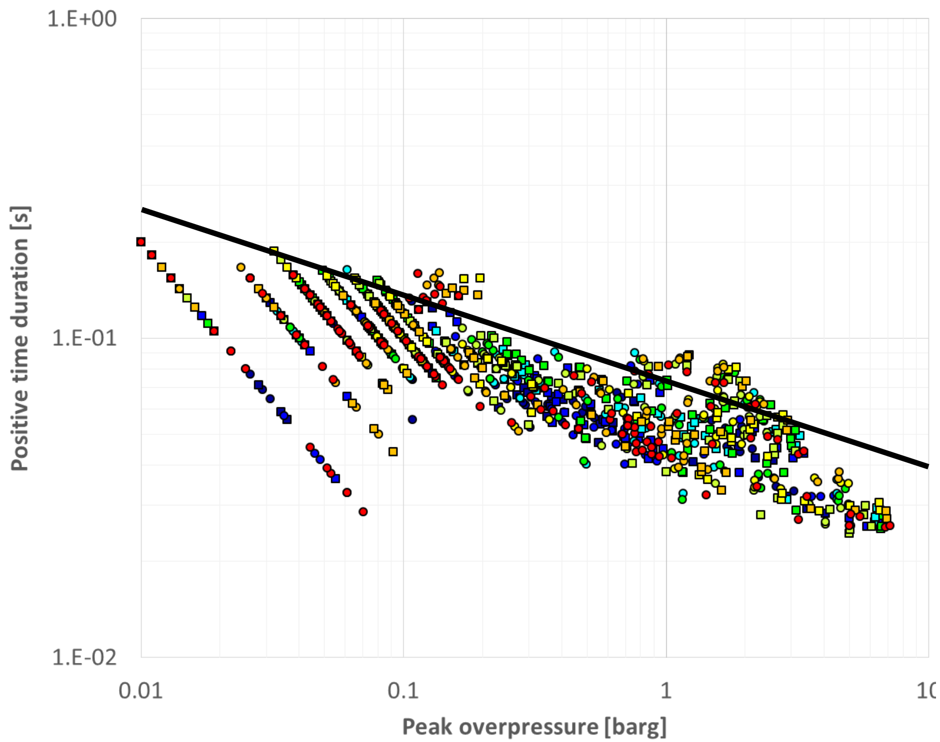
The 10^{-4}/yr overpressure is just part of the DAL definition – need to consider the dynamic behaviour with respect to the duration of the blast and how the blast might travel across the blast wall.

Contour plot of 10^{-4}/yr peak overpressure



Selection of representative 10^{-4}/yr events

Sensitivity cases relating to flammable volume methodology



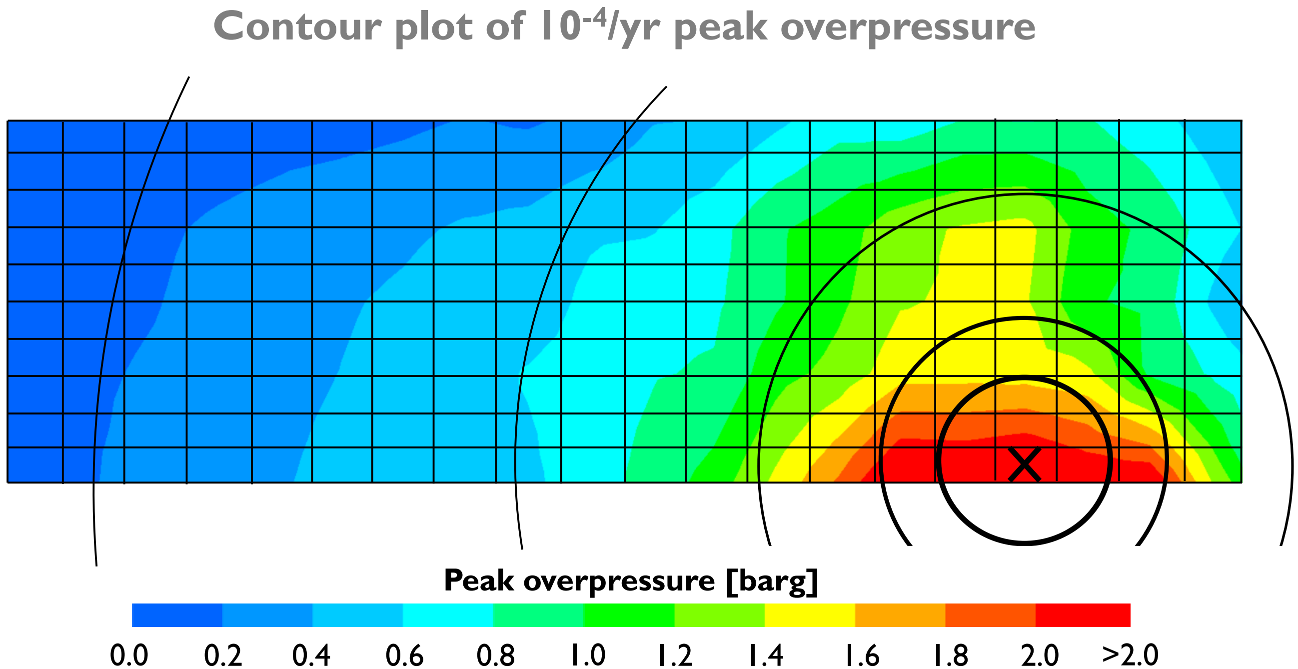
Scatter plot showing time duration of the positive blast phase with peak overpressure

Selection of representative 10^{-4}/yr events

- The 10^{-4}/yr overpressure is just part of the DAL definition – need to consider the dynamic behaviour with respect to the duration of the blast and how the blast might travel across the blast wall
- Identifying trends from the underlying explosion data set can allow us to define the associated time duration of the positive blast phase
- The same approach can be used for the negative blast phase, so that the shape of a (triangulated) 10^{-4}/yr pseudo-blast can be fully described
- A blast, however, will not impinge everywhere instantaneously.

Selection of representative 10^{-4}/yr events

If it can be assumed that the initial impingement is at the location of the peak, the time delay across the blast wall can be included into the pseudo-event blast behaviour.

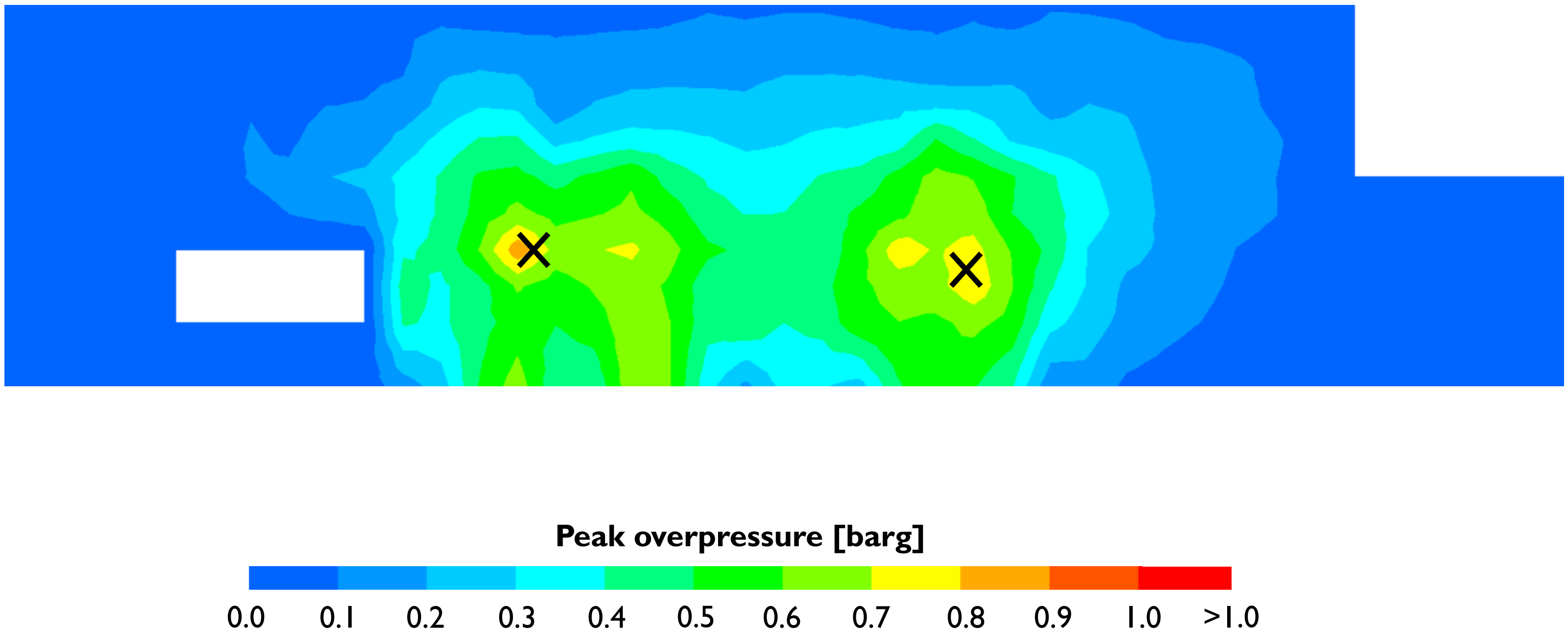


Selection of representative 10^{-4}/yr events

- If it can be assumed that the initial impingement is at the location of the peak, the time delay across the blast wall can be included into the pseudo-event blast behaviour, based upon an assumption of the local speed of sound
- What happens if there are two local peaks in the 10^{-4}/yr peak overpressure?

Selection of representative 10^{-4}/yr events

Contour plot of 10^{-4}/yr peak overpressure



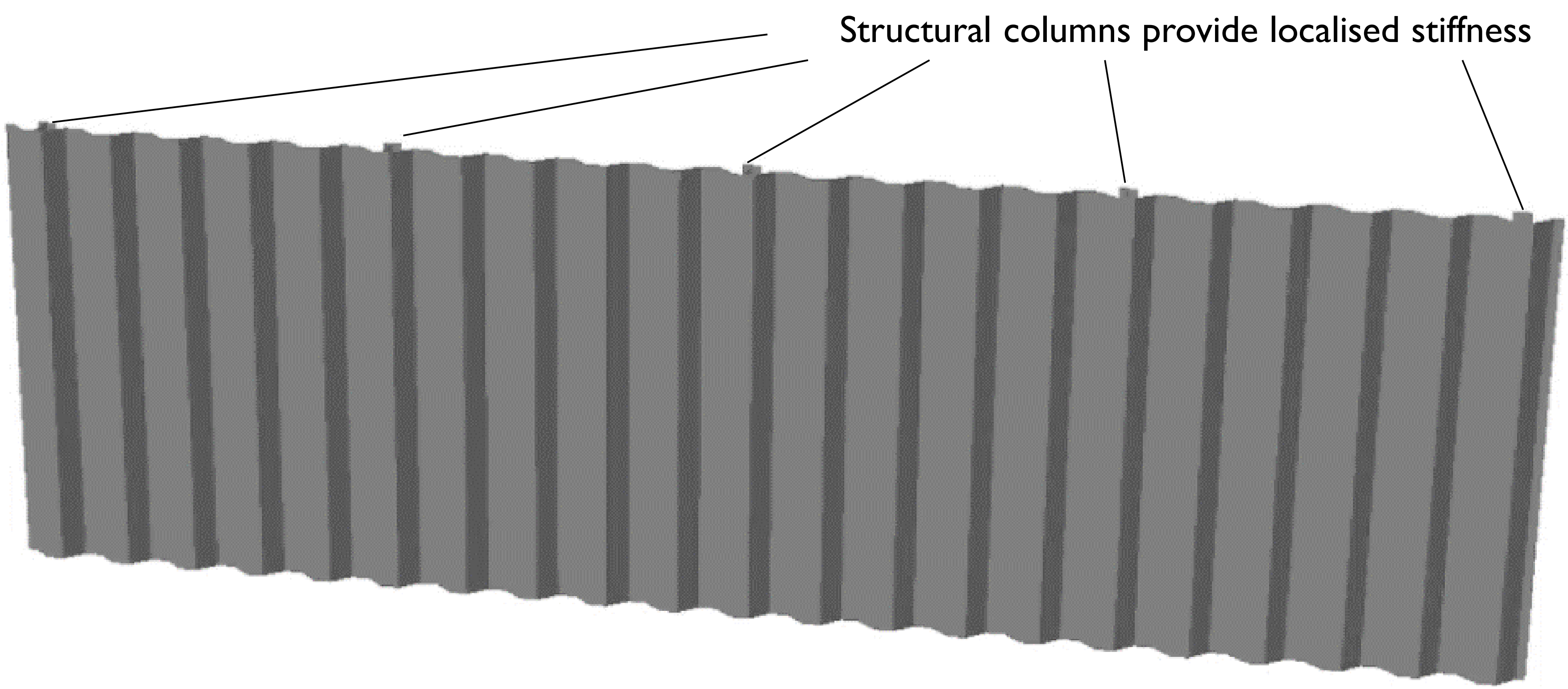
Agenda

- Acknowledgements
- Introduction
- Probabilistic explosion assessment
- Improving the integration of analysis data
- EXCGEN – a software tool to enable an integrated approach
- Sharing/democratisation of analysis data
- 3D risk assessment
- Selection of representative 10^{-4}/yr events
- Probabilistic structural response
- Summary.

Probabilistic structural response

- Rather than construct a single pseudo-event, undertake a probabilistic assessment for the structural response instead:
  - The probability of occurrence for each underlying explosion event is known
  - Use FEA to simulate the structural response for (every?) explosion event
  - Compile exceedance curves for structural measures (for example, stress and/or deflection) at every monitor panel
  - Compile into plots of 10^{-4}/yr stress and/or deflection
- No need to make assumptions regarding the pseudo-event
- Faster computers at least make this a realistic alternative.

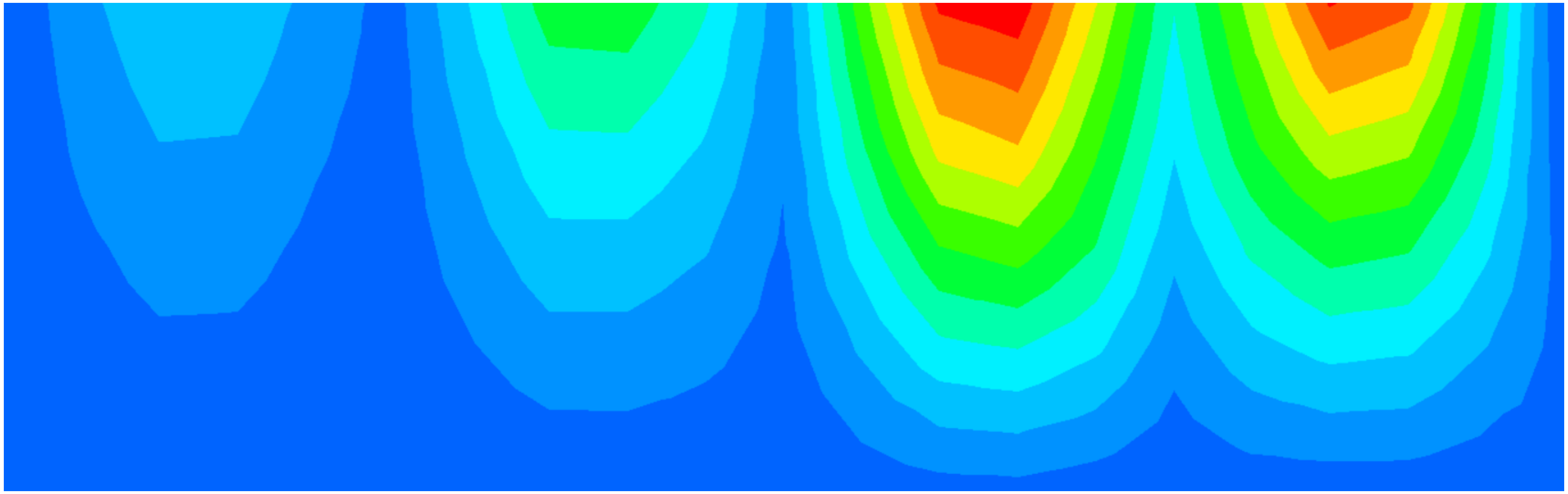
Probabilistic structural response



Structure of the blast wall

Probabilistic structural response

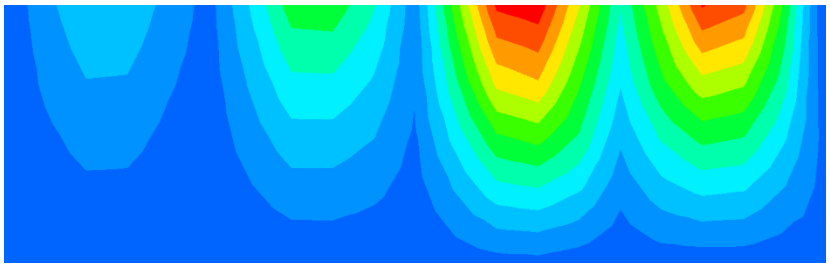
Contour plot of 10^{-4}/yr deflection
(using a probabilistic structural response approach)



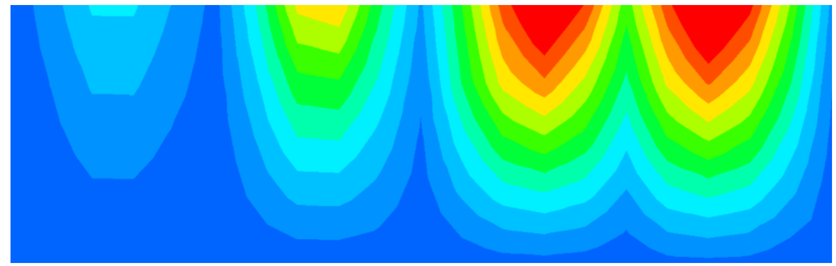
Deflection [m]

Probabilistic structural response

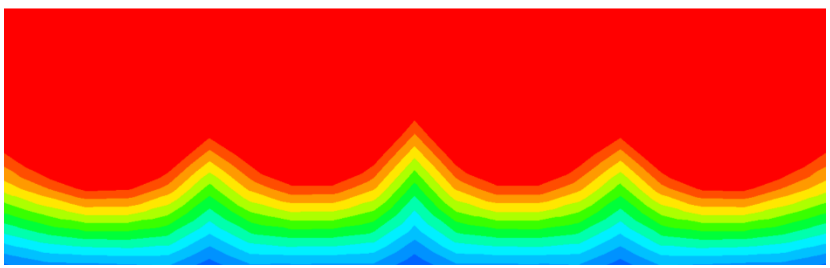
Contour plot of 10^{-4}/yr deflection



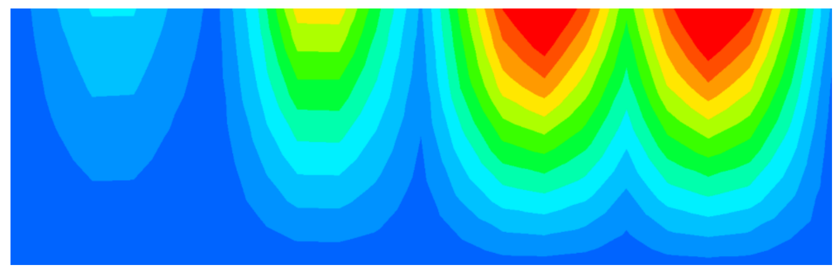
Using a probabilistic structural response approach



Using the 10^{-4}/yr pseudo-event without time delay



Traditional approach – uniformly applying the 10^{-4}/yr overpressure (2 barg) from the exceedance curve



Using the 10^{-4}/yr pseudo-event with time delay

Deflection [m]

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Summary

- CFD is used for many types of technical safety study, including probabilistic explosion assessments – ventilation, dispersion and explosion
- There is a huge amount of predictive data generated during the course of a probabilistic explosion assessment that could be extremely useful to the structural engineer
- This is often not utilised because the probabilistic explosion assessment and the structural design are typically undertaken by different parties and the sharing of information has not been easy.

Summary

- The industry needs a tool to provide a robust method of implementation of the probabilistic methodology outlined in NORSOK Z013
- Abercus has developed the **EXCGEN** tool for this purpose
- Gexcon is currently developing **RISK** for the same purpose
- Other tools may follow?
- **EXCGEN** enables:
  - Sharing and associated democratisation of analysis data – sensitivities
  - 3D risk assessment
  - Probabilistic structural response.

Summary

- The more you look at something, very often, the more interesting it gets – when information becomes easily available other points of discussion follow:
  - How to select representative 10^{-4}/yr events?
  - How to construct 10^{-4}/yr pseudo-events?
  - Is it worth pursuing a probabilistic structural response approach?

    For the example considered there is reasonable agreement between the pseudo-event and probabilistic structural response approaches, but we need to consider a much wider range of examples to determine whether this is generally the case
- A role for NAFEMS/FABIG?

Thank you for listening

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