Modelling Hazardous Consequences of a Shale Gas Well Blowout

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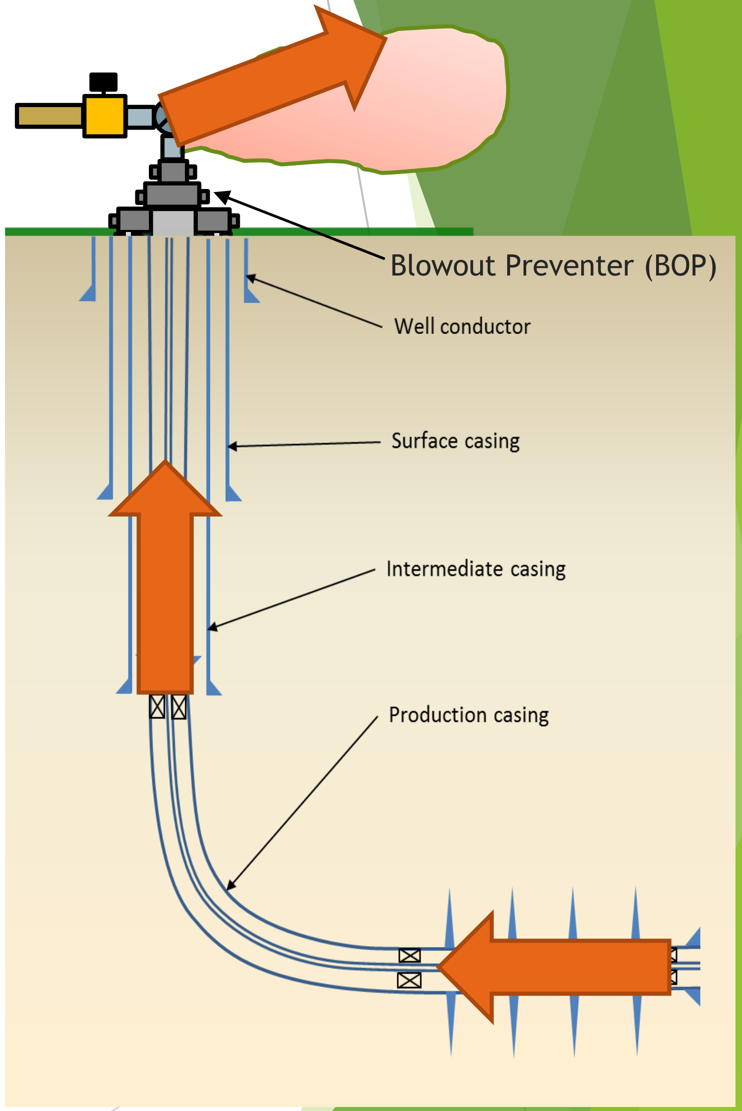
Presentation Scope

- Motivation and objectives
- Well blowout modelling methodology
  - Outflow model
  - Jet fires
  - Explosions
- Results of the case study
- Conclusions

Background and Motivation

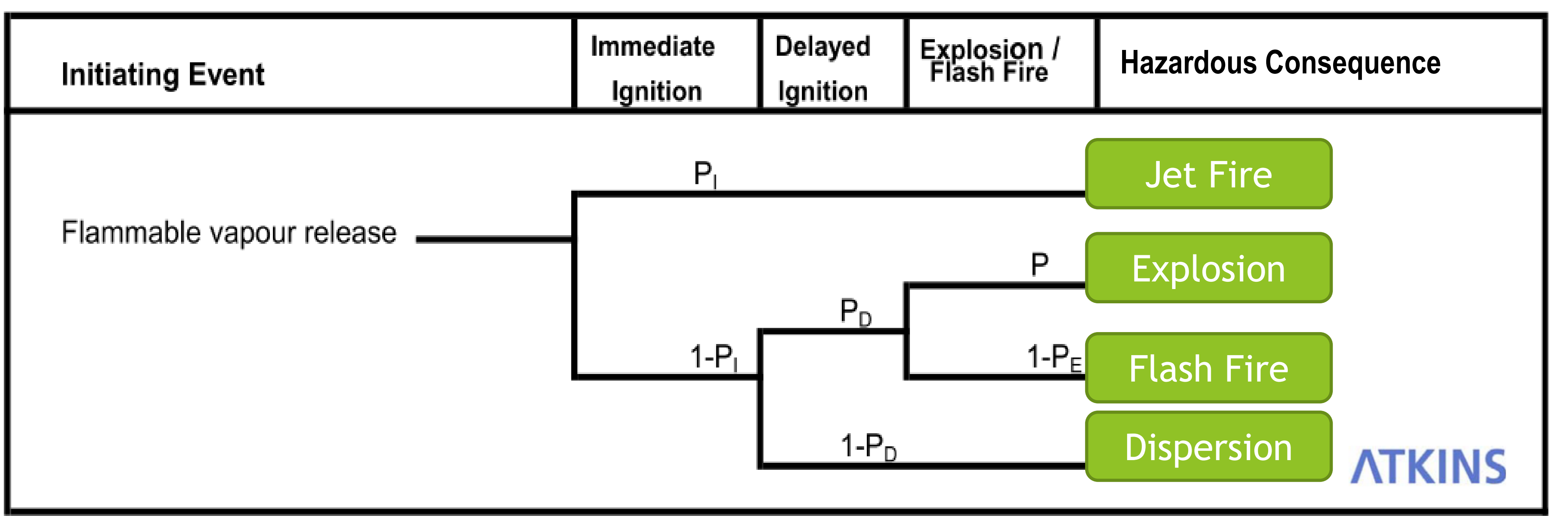
Eagle Ford shale in Texas

http://the-earth-story.com/post/114862966776/drilling-shale-and-blowouts-this-is-a-classic



- Failure of shale gas well facilities can have catastrophic consequences for people and environment
- Statistics shows that majority of blowouts happen during drilling when "pressure kicks" propagate into the well and BOP fails to divert the gas to a flare stack
- Safe design of Major Hazards installations requires quantitative risk assessment (QRA) based on models predicting the hazards

Event tree for gas release consequence modelling

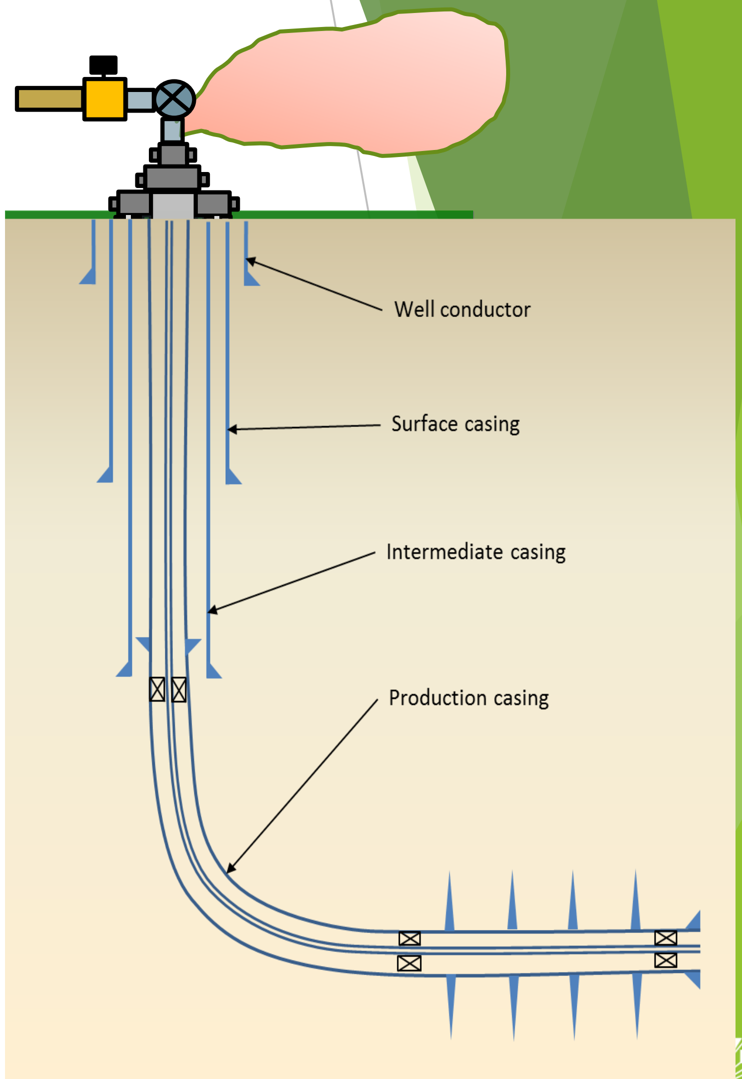


Objectives

- Development of model for simulating the transient outflow of shale gas in the event of a wellhead blowout
- Application of the wellhead blowout model to a specific EU well to assess the hazards associated with transient fire and explosion over-pressure

Modelling challenges

- Model of the well discharge:
  - Transient compressible multi-phase flow;
  - Heat transfer through casing and viscous friction;
  - Complex multicomponent hydrocarbon mixtures;
  - Complex geometry of the well;
- Modelling jet fires and explosion:
  - 3D radiation profiles
  - Coupling with the outflow model



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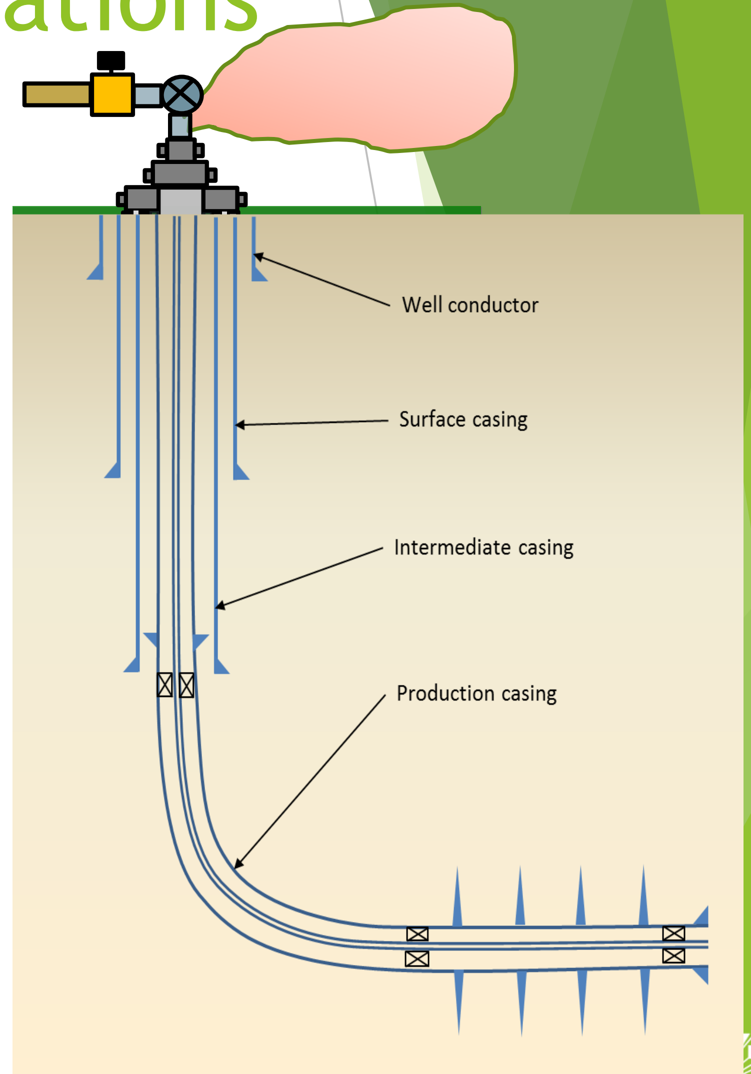
The well discharge flow model equations

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} = 0$$

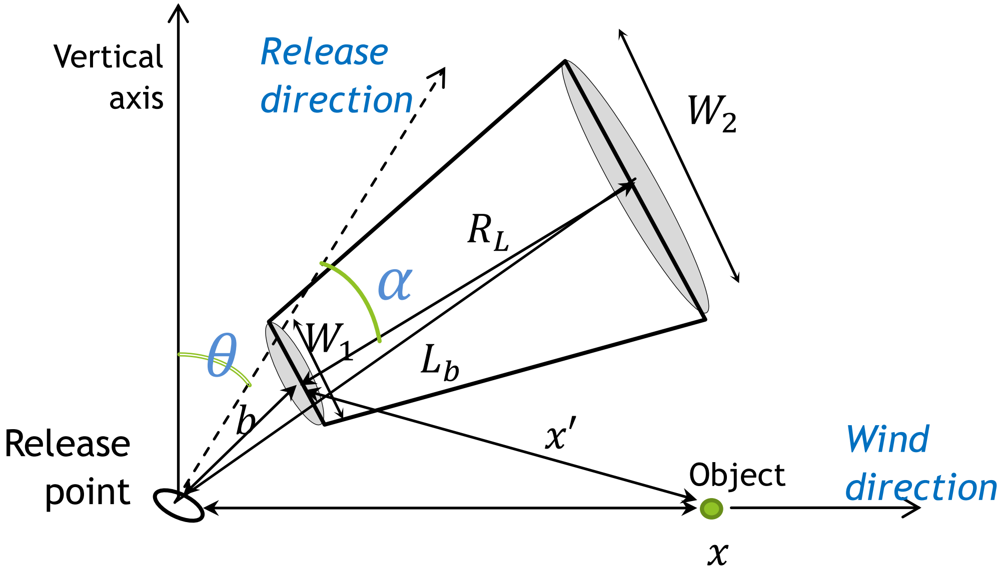
$$\frac{\partial \rho u}{\partial t} + \frac{\partial (\rho u^2 + p)}{\partial x} = -\rho g_x - \frac{f_w \rho u^2}{D}$$

$$\frac{\partial \rho E}{\partial t} + \frac{\partial (\rho u E + u p)}{\partial x} = -\rho u g_x - \frac{f_w \rho u^3}{D} + q_w$$

where ρ, u, E and p are respectively the fluid density, velocity, total specific energy and pressure, x the spatial coordinate, t is the time, D is the internal diameter, g_x is the gravity force, q_w is the heat flux, and f_w is the Fanning friction factor



Jet fire modelling



Schematics of the frustum representing a jet (after Chamberlain, 1987)

b is the lift-off distance (m);

W_1 and W_2 are the diameters of the frustum (m);

R_L is the visible flame length (m);

L_b is the flame length (m);

θ is the angle between the release direction and the vertical axis;

α is the tilt angle of the jet flame;

Jet fire – thermal radiation model

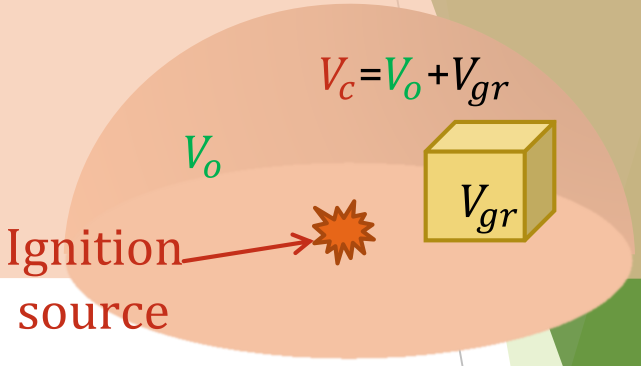
The radiated flux at the receiver object:

$$\boxed{q = \tau \times VF \times S_\infty}$$

VF	is the view factor;
τ	is the atmospheric transmissivity;
$S_\infty = \frac{F_S Q}{A}$	is the average surface emissive power (kW m^{-2});
$Q = \dot{m}\Delta H_c$	is the power radiated into atmosphere (kW);
ΔH_c	is the heat of combustion (kJ kg^{-1}) ;
$\dot{m}$	is the mass flow rate (kg s^{-1});
$F_s = 0.21e^{-0.00323u_j} + 0.11$	is the fraction of heat emitted.

Explosion modelling

V_c is the volume of the released stoichiometric cloud (m^3)
V_o is volume of unobstructed part of the cloud (m^3)
V_{gr} is volume of obstructed part of the cloud (m^3)



$$V_c = \frac{Q_{ex}}{\rho \, \alpha_s}$$

Q_{ex} is the amount of vapour released (kg)
ρ is the cloud density (kg/m^3)
α_s is the air-fuel stoichiometric concentration (vol%)

$$E = E_v \, V$$

E is the energy of the blast wave (J/m^3)
E_v is the heat of combustion of a stoichiometric hydrocarbon–air mixture (3.5 MJ/m^3)
V is the volume of the cloud in specific region of interest (m^3)

$$r_o = \sqrt[3]{\frac{3}{2\pi} \frac{E}{E_v}}$$

r_o is the radius of the released vapour cloud (m)

$$r' = r \sqrt[3]{p_a / E}$$

r' is dimensionless radial distance to the explosion source (-)

$$P'_{so} = P_{so} / p_a$$

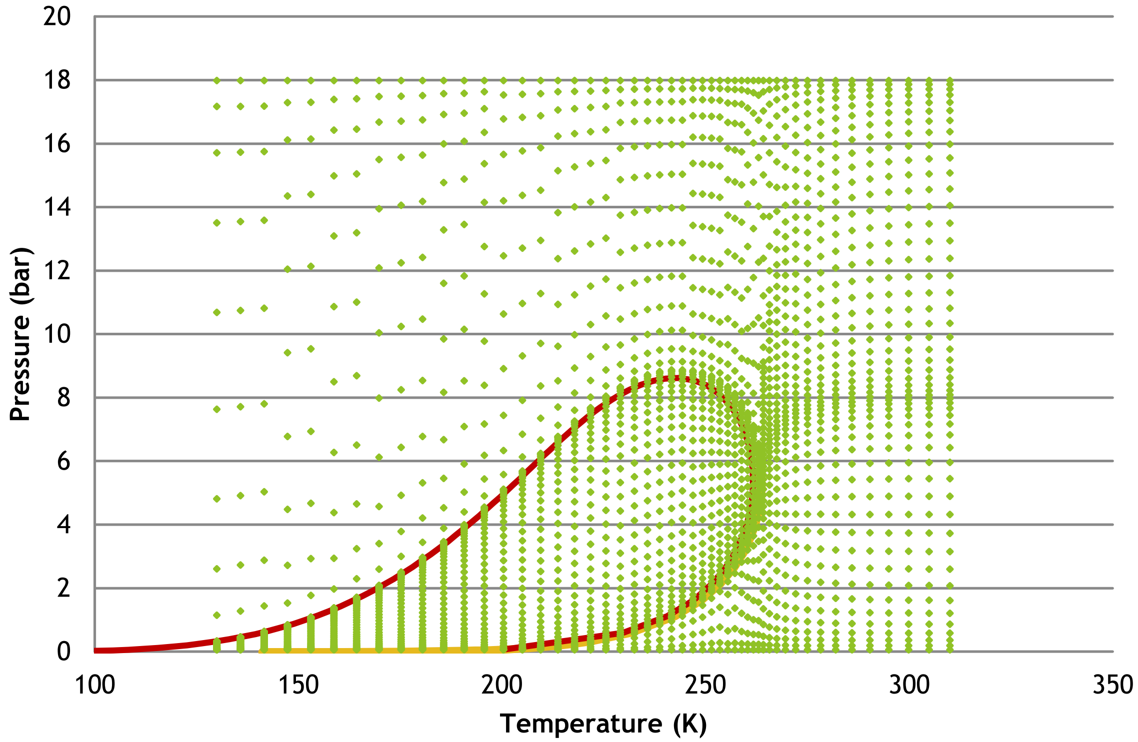
P'_{so} is the blast strength (-)
p_a is the ambient pressure (Pa)
P_s is the peak overpressure (Pa)

Explosion overpressure

$$P_s = f(P'_{so}, r')$$

Physical properties of the fluid

- Fluid phase properties are simulated using an accurate equation of state for a typical natural gas composition



CH_4 - 90 mol%

C_2H_6 - 4.5mol%

C_3H_8 - 3.5mol%

C_4H_{10} - 2mol%

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- **Case study**
- Results and Conclusions

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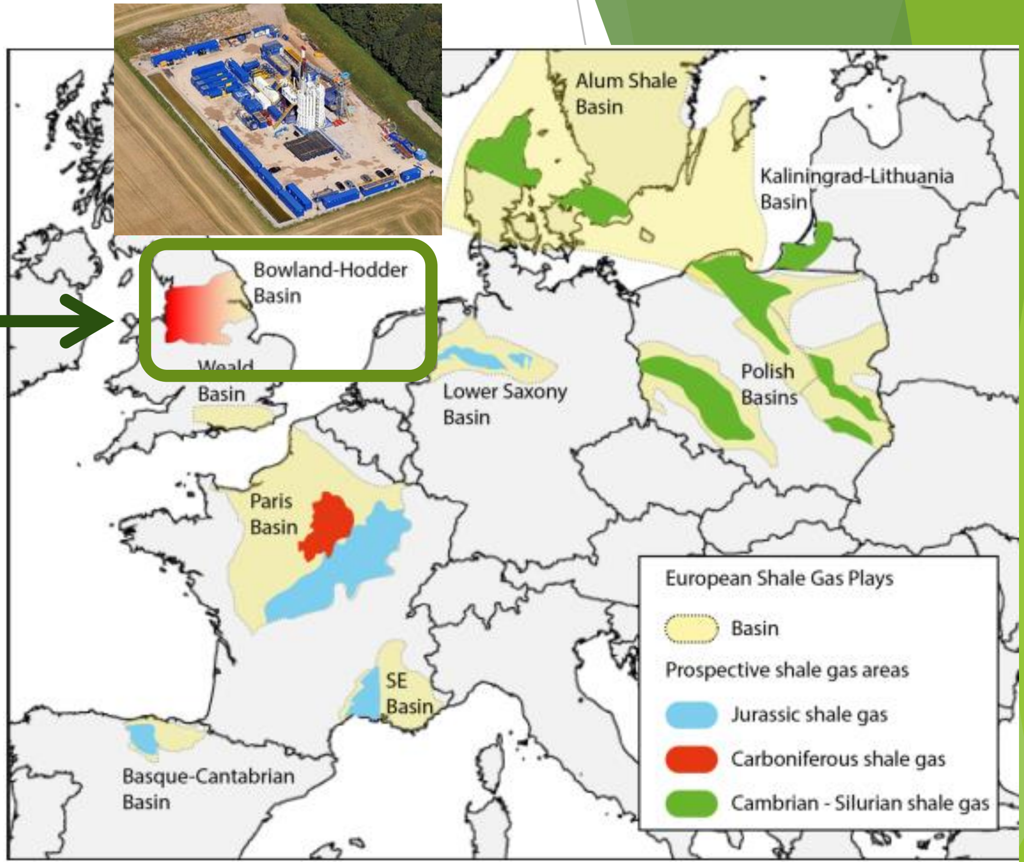
Case study - Methodology

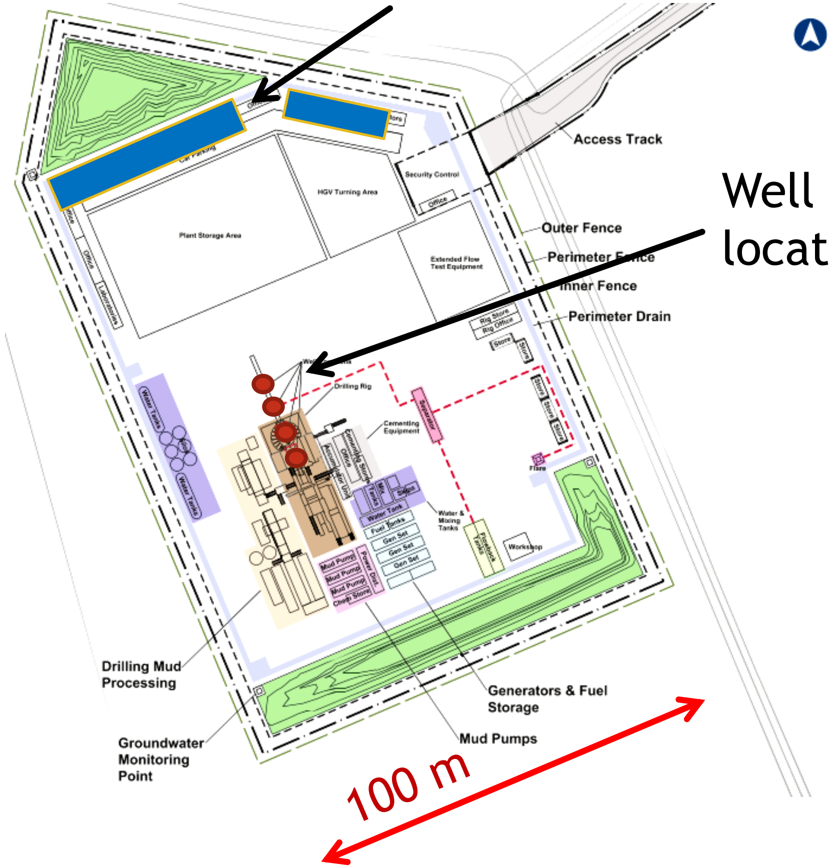
- **Cuadrilla Roseacre Wood** shale gas exploration project
  - ✓ Well geometry
  - ✓ Location and weather conditions
  - ✓ Formation pressure and temperature

- Consequence modelling for possible deviations from the nominal reservoir conditions, *i.e.* estimated magnitudes of "pressure kicks"



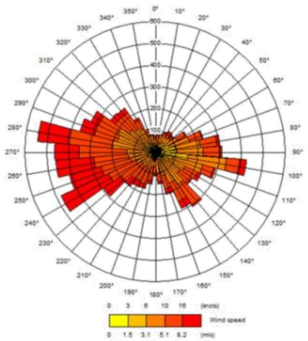
Map of Europe showing shale rock sedimentary basins in Europe (SXT Deliverable 2.2)

Well site layout and weather conditions

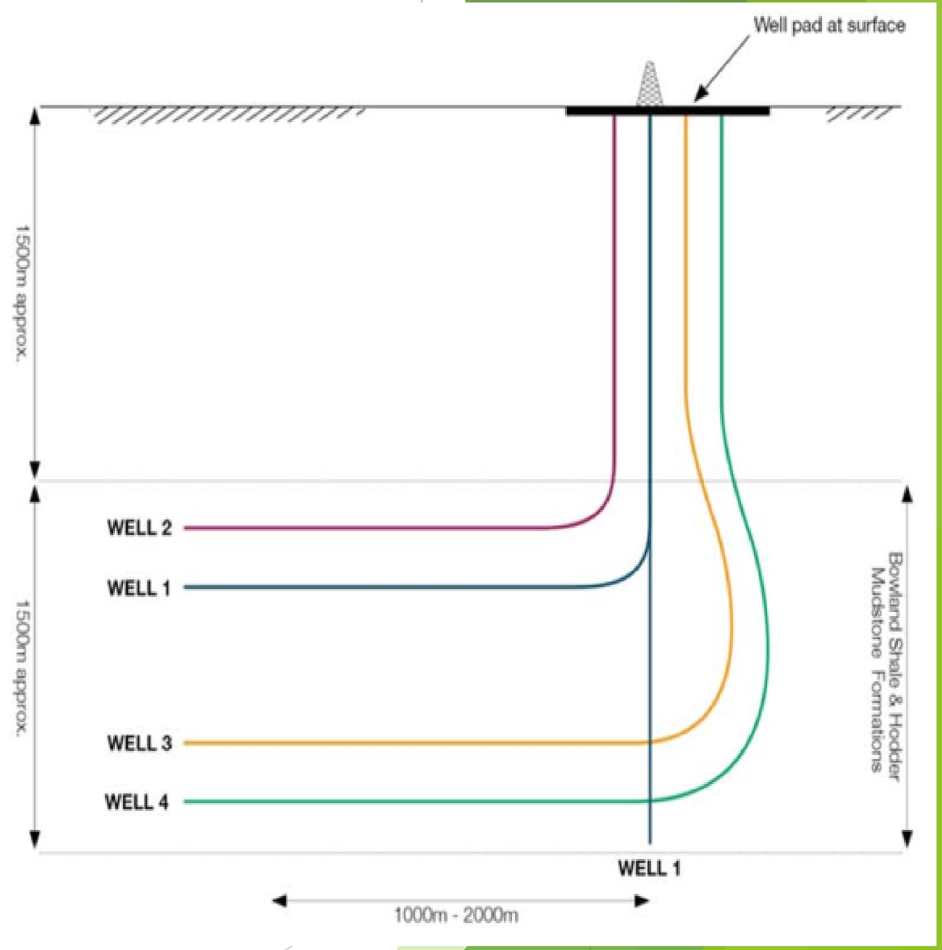


Offices

Well locations



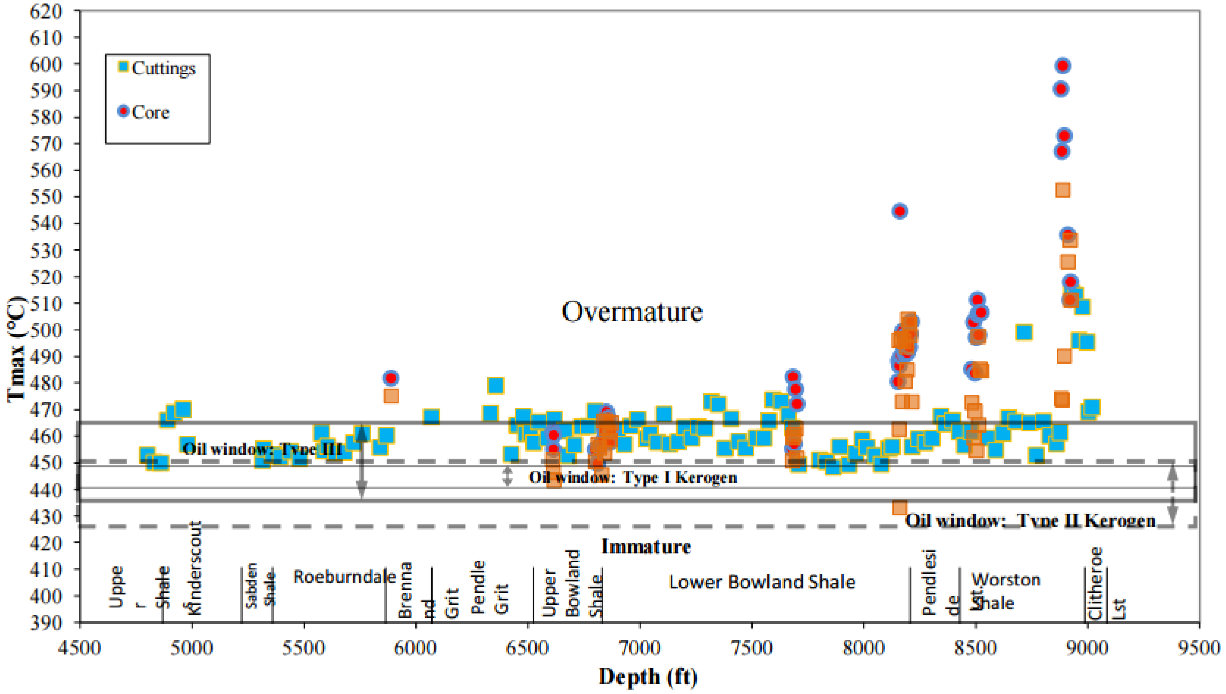
Wind rose of meteorological data at Blackpool meteorological station, 2012

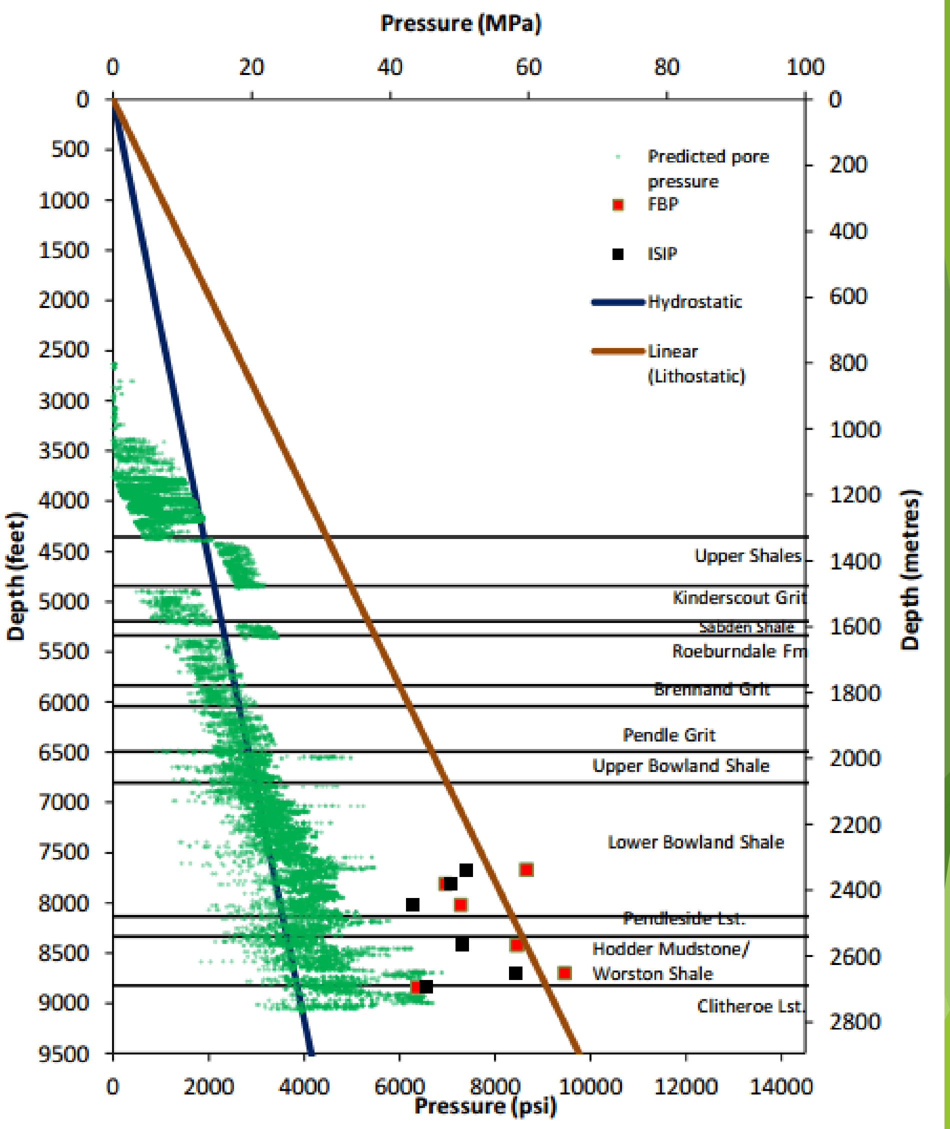


Schematic of the drilling site layout and the shale gas exploration wells (Cuadrilla Elswick Ltd).

Reservoir conditions

- Reservoir pressure hydrostatic gradient ~ 100 bar/km,
- Reservoir temperature gradient ~ 23°C/km.

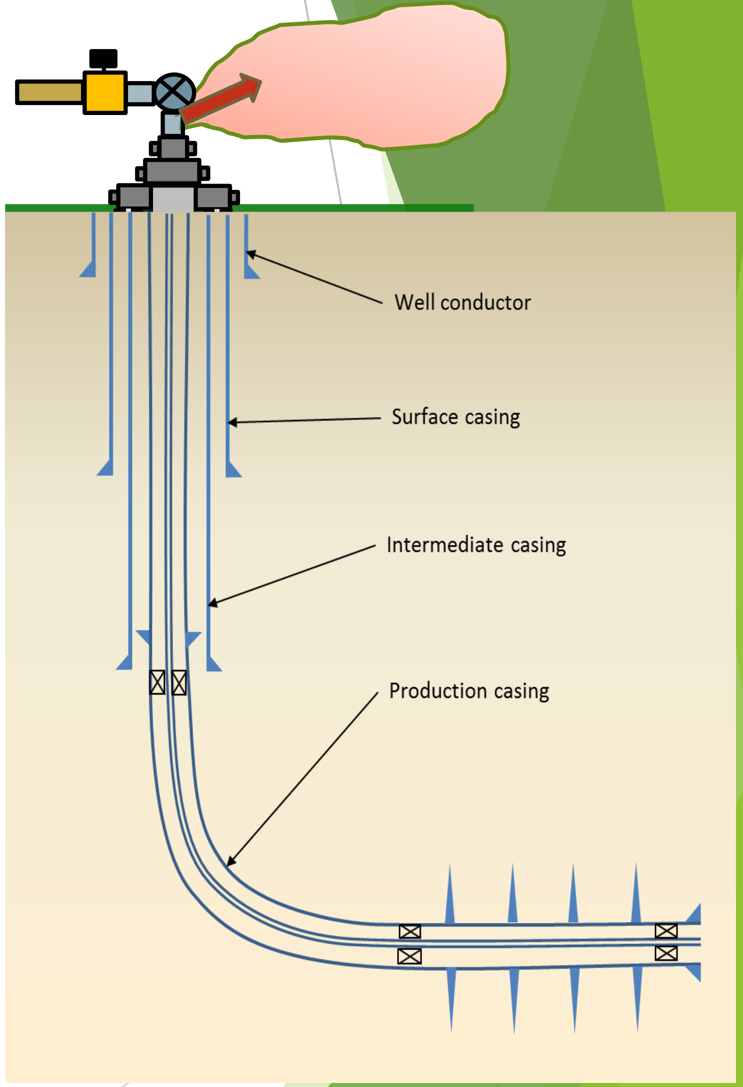




Formation temperature and pressure
(UK Shale Gas Exploration, Cuadrilla Resources Ltd)

Case study parameters

Parameters	Value
Well parameters	
Overall length Material of construction Wall surface roughness Heat transfer coefficient External diameter Internal diameter Wall thickness Orientation relative to horizontal	4000 m Mild steel 0.05 mm 0 W/m^{2}K (Adiabatic) 127 mm 114.4 mm 6.2 mm 90 ° (vertical)
Reservoir parameters	
Temperature Pressure	343 K 200 – 600 bar
Ambient conditions	
Temperature Pressure Wind Speed Relative Humidity of air	293.15 K 1.01 bara 0 -10 m/s 50%



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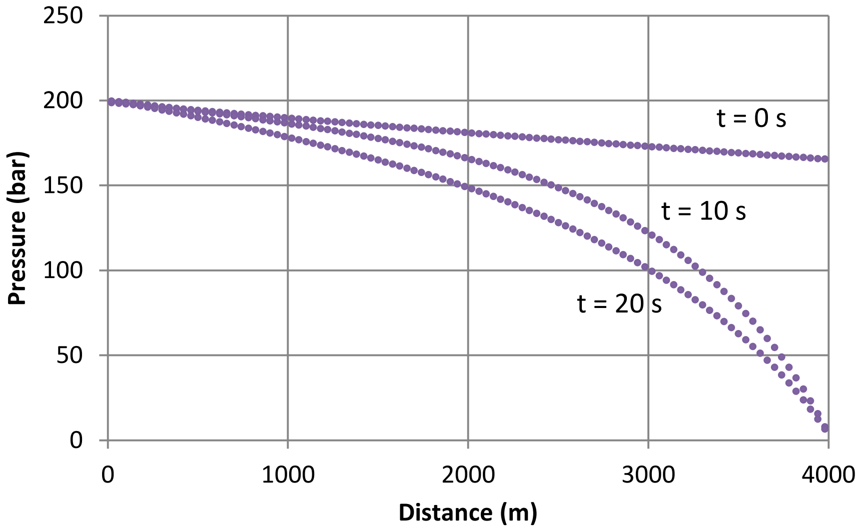
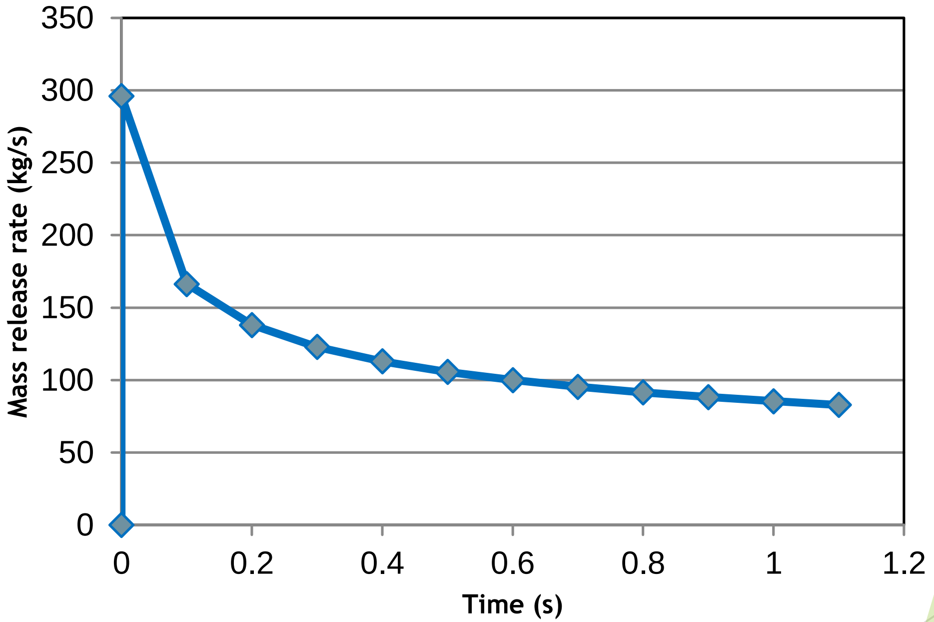
Outflow simulation results



The flow establishes very quickly in time

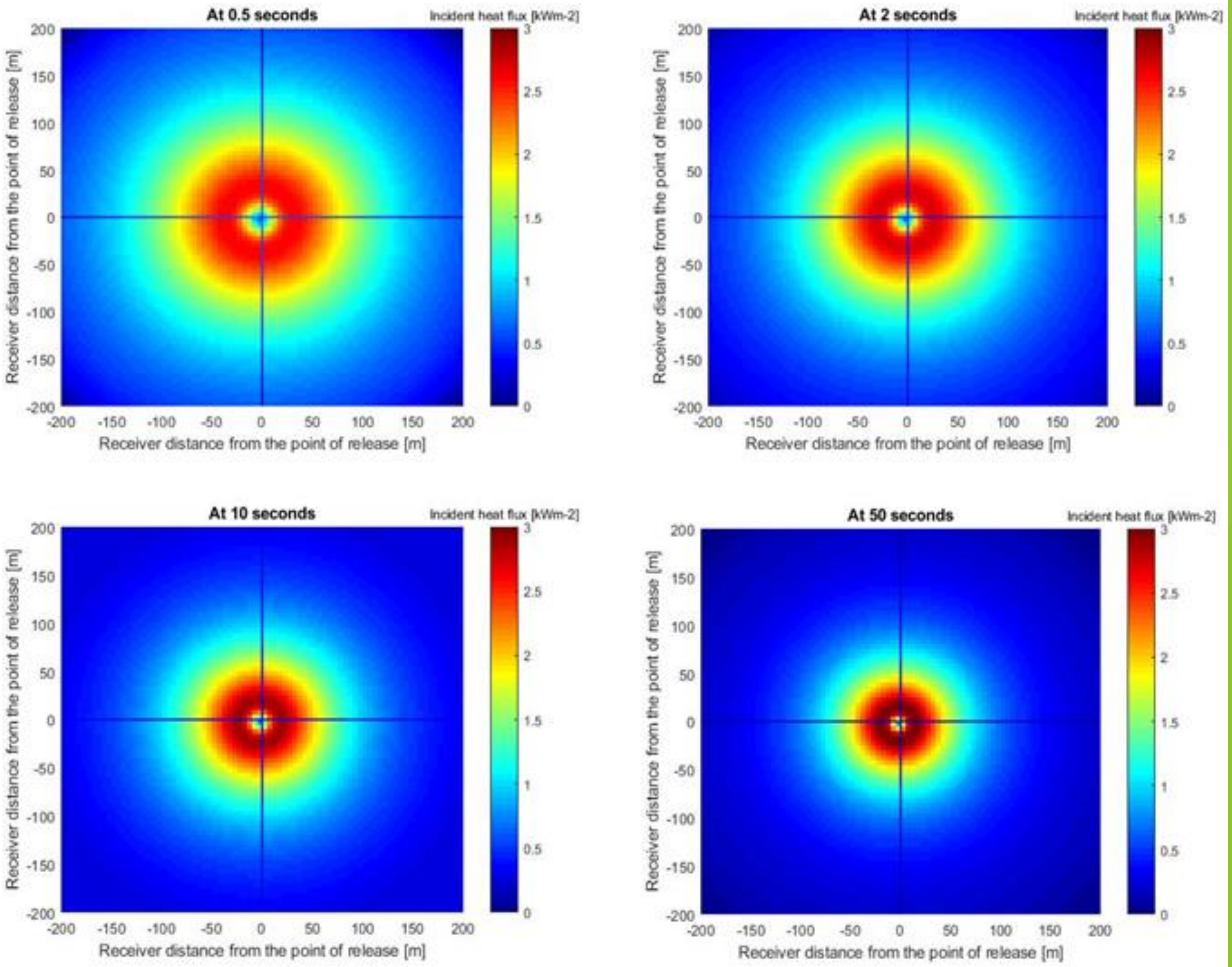


The results of *transient* simulations of the outflow (pressure, flowrate, phase composition, *etc*) are used as inputs for consequence modelling

Thermal radiation contours

Incident heat flux contours at the ground level around vertical flame formed at the wellhead (0;0), predicted at various times following the blowout.

Instantaneous ignition.
Wind speed = 0 m/s.



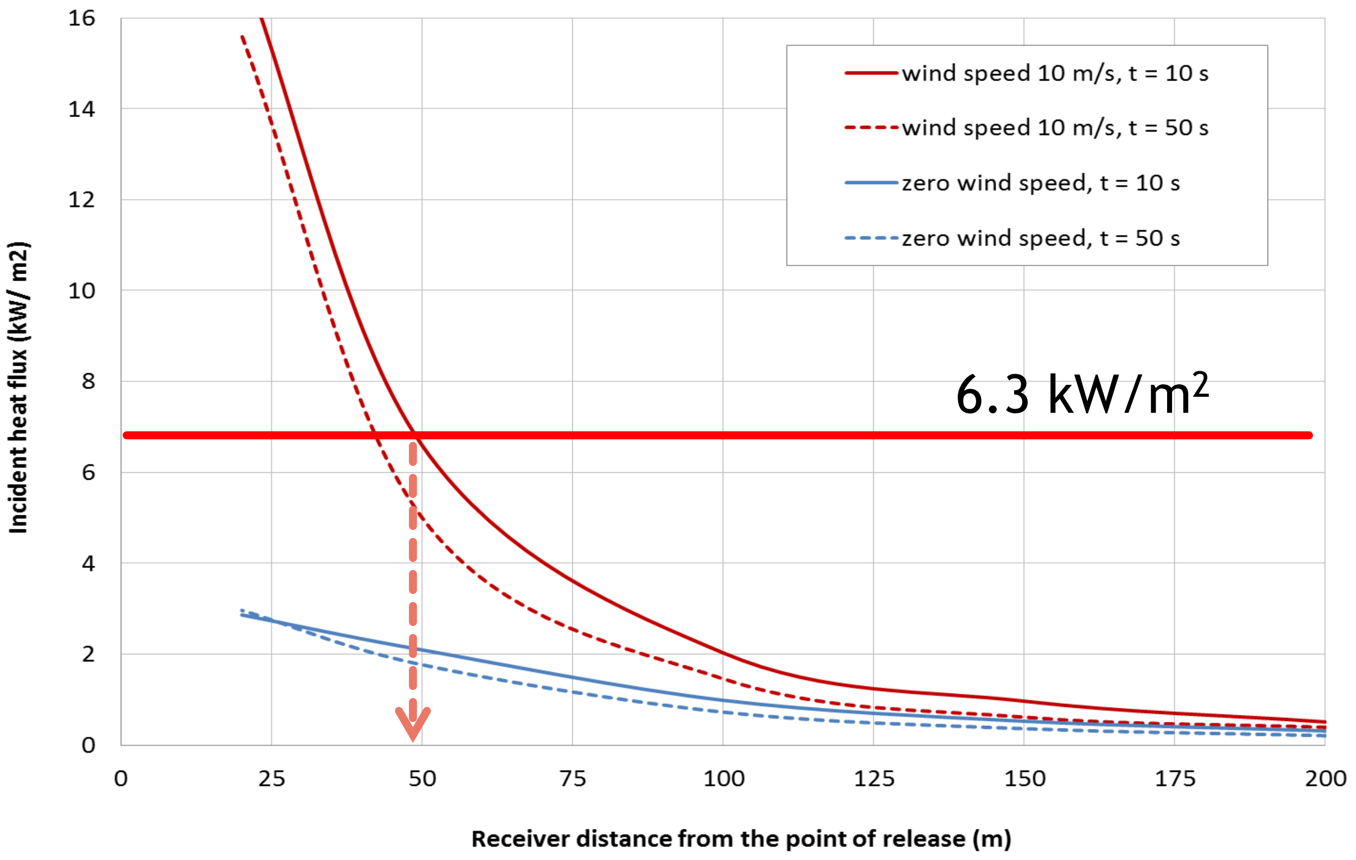
At 0.5 seconds

At 2 seconds

At 10 seconds

At 50 seconds

Thermal radiation – safe distances



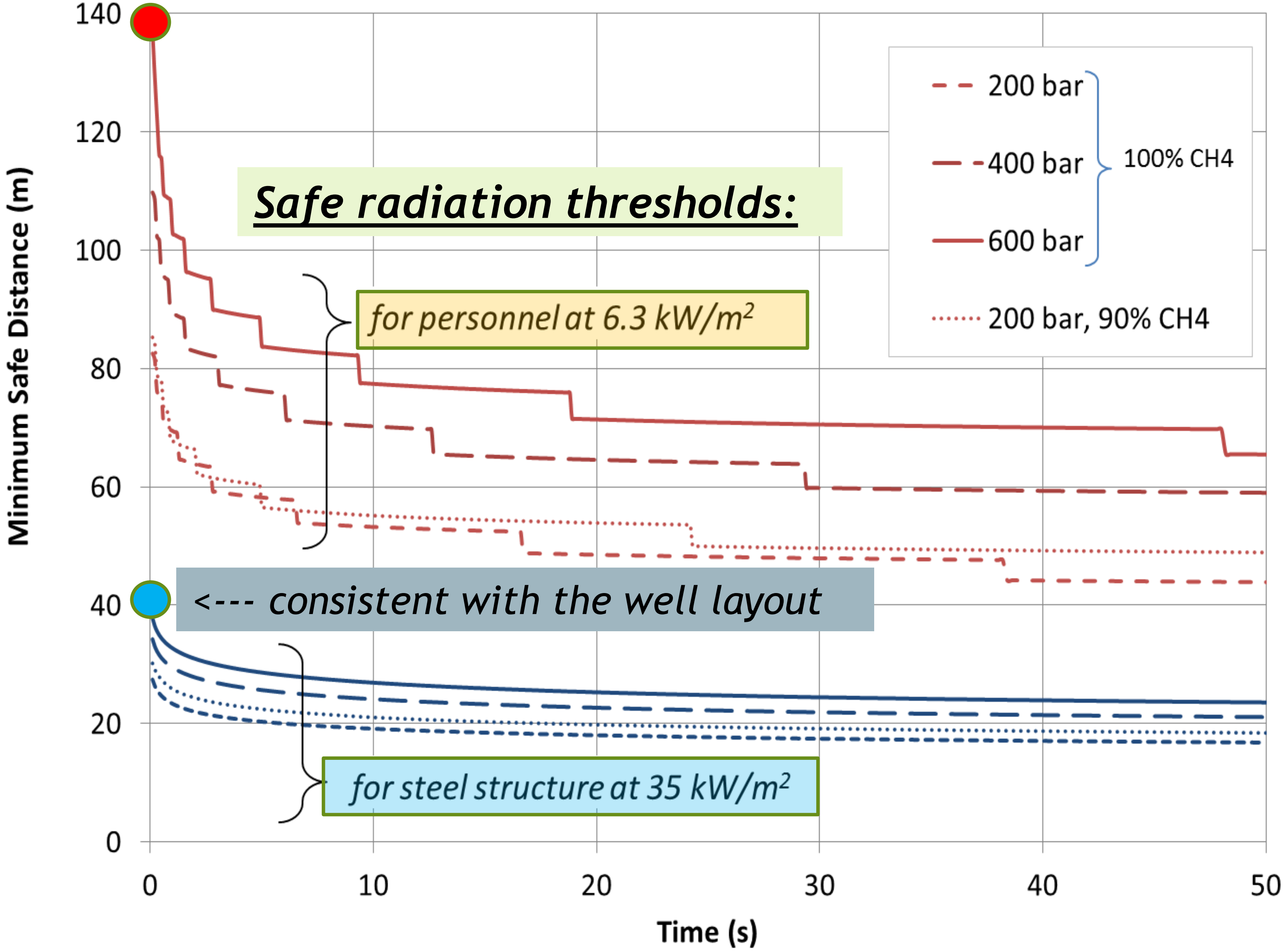
Safe distance can be determined for a given radiation threshold

The incident radiation heat flux as a function of the receiver distance, predicted for the vertical well blowout

Thermal radiation – safe distances

Safe distances to a vertical jet flame for *personnel* and *steel structures*.

Wind speed 10 m/s.
Flat terrain, no firewalls.



Explosion overpressure hazards

Potential damage to health caused by peak overpressure for various types of locations

Type of location	Peak overpressure (mbar)	Potential damage
People in the open	300	Eardrum rupture
	1000	Picked up and thrown; likely fatality
People in normal buildings	70 - 250	Significant likelihood of fatality due to masonry collapse and projectiles, particularly glass
Blast resistant buildings	> 200	Some likely fatality
Blast proof buildings	> 1000	Some likely fatality

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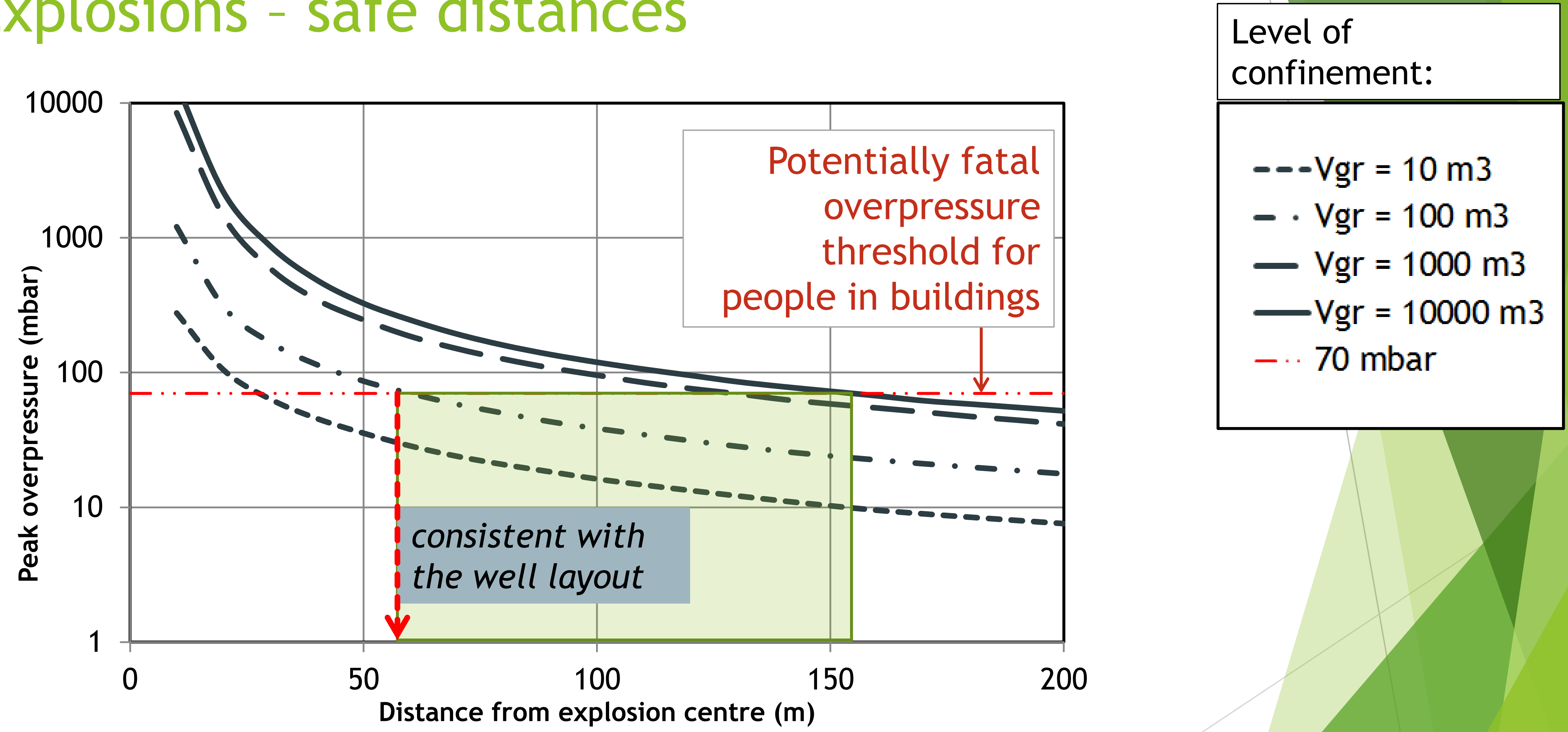
Explosions – safe distances



Potentially fatal overpressure threshold for people in buildings

consistent with the well layout

Simulated explosion overpressures as a function of distance from the explosion source at the wellhead for various levels of confinement

Conclusions

- A methodology has been developed to predict hazards associated with shale gas wellhead blowout
- The methodology enables prediction of
  - the transient flow rate,
  - the thermal radiation from jet fires, and
  - the explosion overpressure levels
- The methodology was applied to evaluate safety hazards for a hypothetical blowout scenario for a realistic shale gas well

Thank you

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