OIL & GAS

Eksplosjonsrisiko, værbeskyttelse og optimalisering av design

HMS utfordringer i Nordområdene – Arbeidsseminar 4

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20 May 2014

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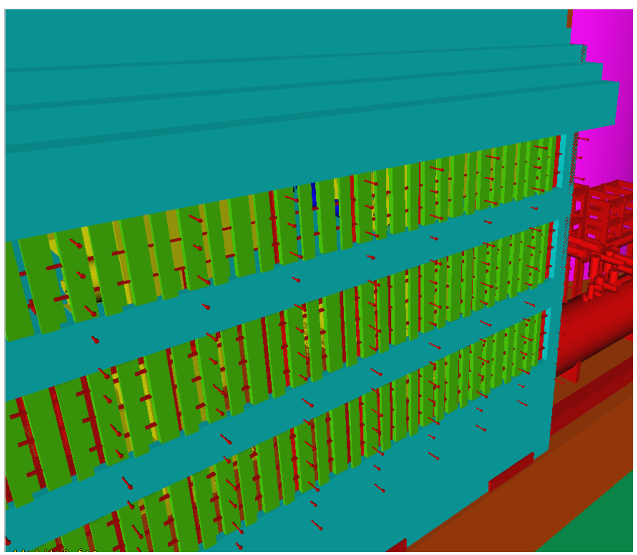
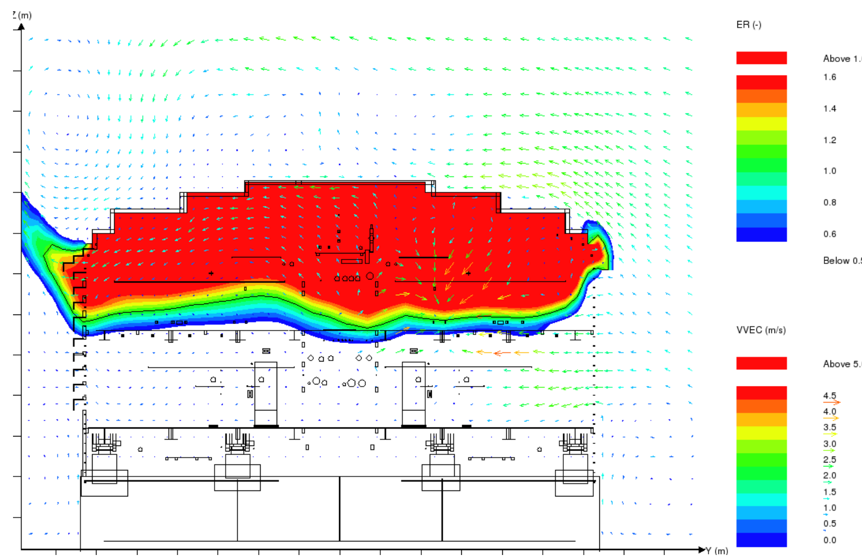
- Explosion risk analysis as decision making tool
  - Explosion theory
  - Example FPSO in arctic
- Wind chill and outdoor operations
  - Theory and principles
- Typical scope ERA and Wind Chill Analysis
- Optimization of design
  - Improving ventilation with passive and active systems
  - Mitigating explosions
- Summary and recommendations

Main safety challenges in arctic

- Ensure safe design wrt process safety and working environment
- Objectives:
  - Give recommendations and decision support in order to optimize working environment AND safety
  - Comply with regulations



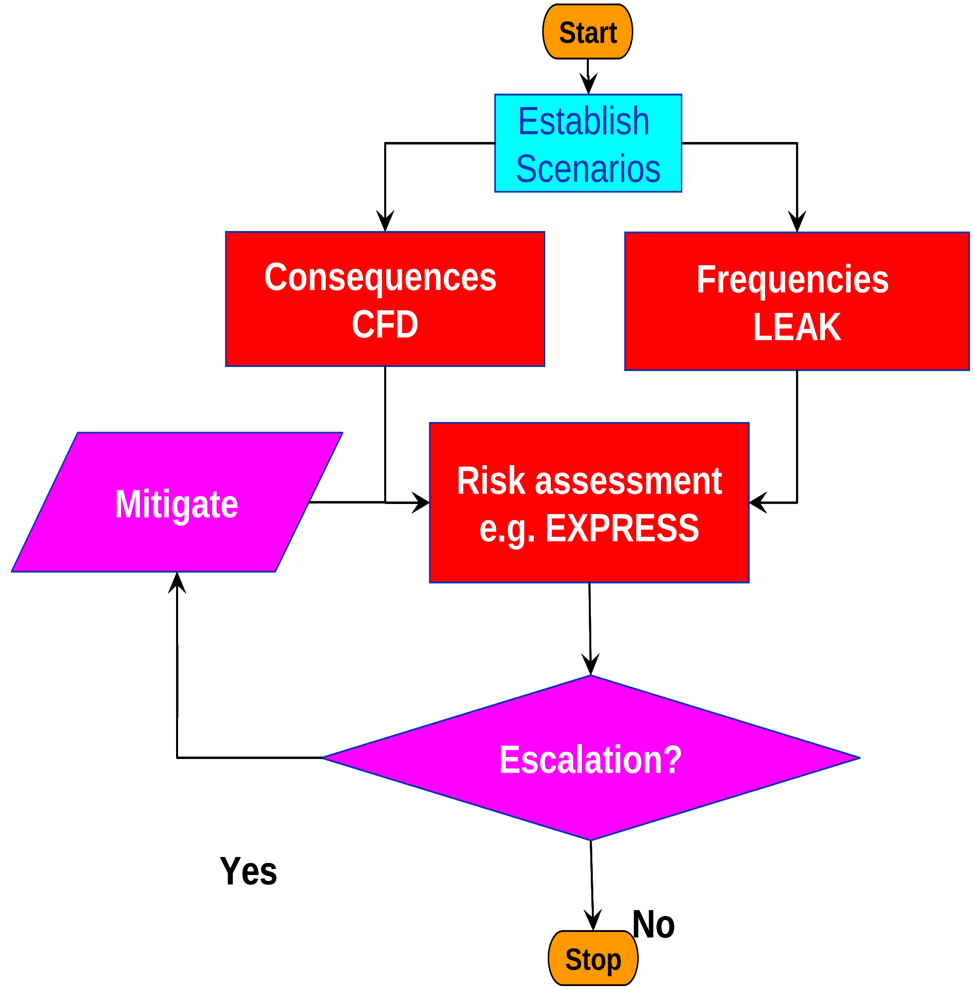


Explosion risk analysis as decision making tool

Overall risk analysis and risk based design procedure

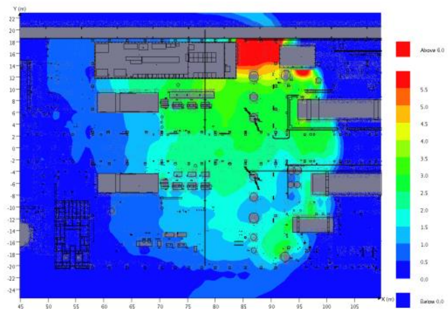
- Break down and organize consequences and frequencies – Examination
- Simulate all events – Risk Analysis

- Point at risk drivers – Diagnosis
- Deliver design improvements
- Find solutions together with contractor



Explosion Risk Analysis approach

EXPLOSION ANALYSIS:



Respons surfaces
- ventilation
- dispersion
- Explosion

Leak frequency analysis

Process conditions and inventories

Wind rose

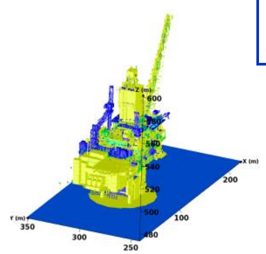
- Gas detectors
- Ignition source control
- ESD system
- Module dim

Geometry modeling

Ventilation

Dispersion

Explosion



Probabilistic analysis:

- DNV program EXPRESS
- Response surfaces
- JIP Ignition model
- Monte Carlo simulations

Sensitivities?

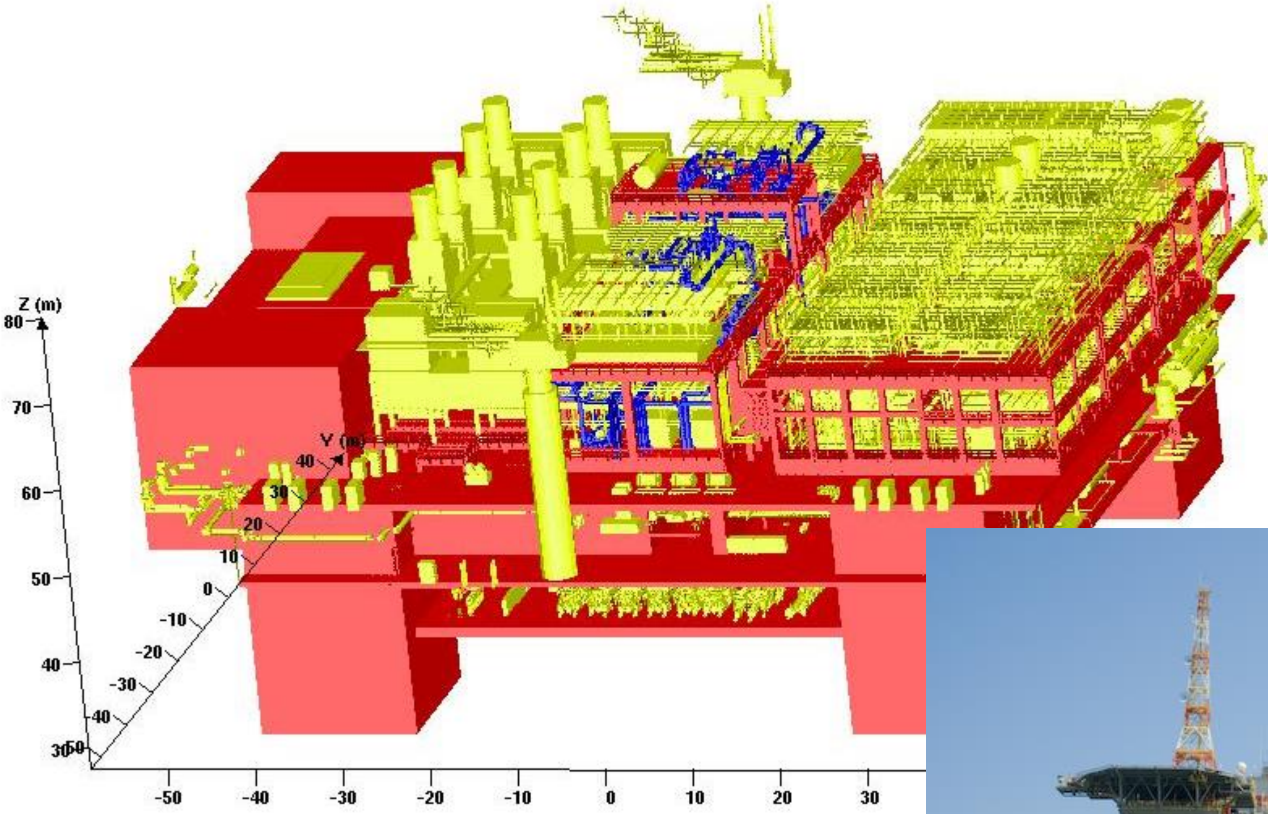
Design effects and recommendations

Explosion Design Accidental Loads

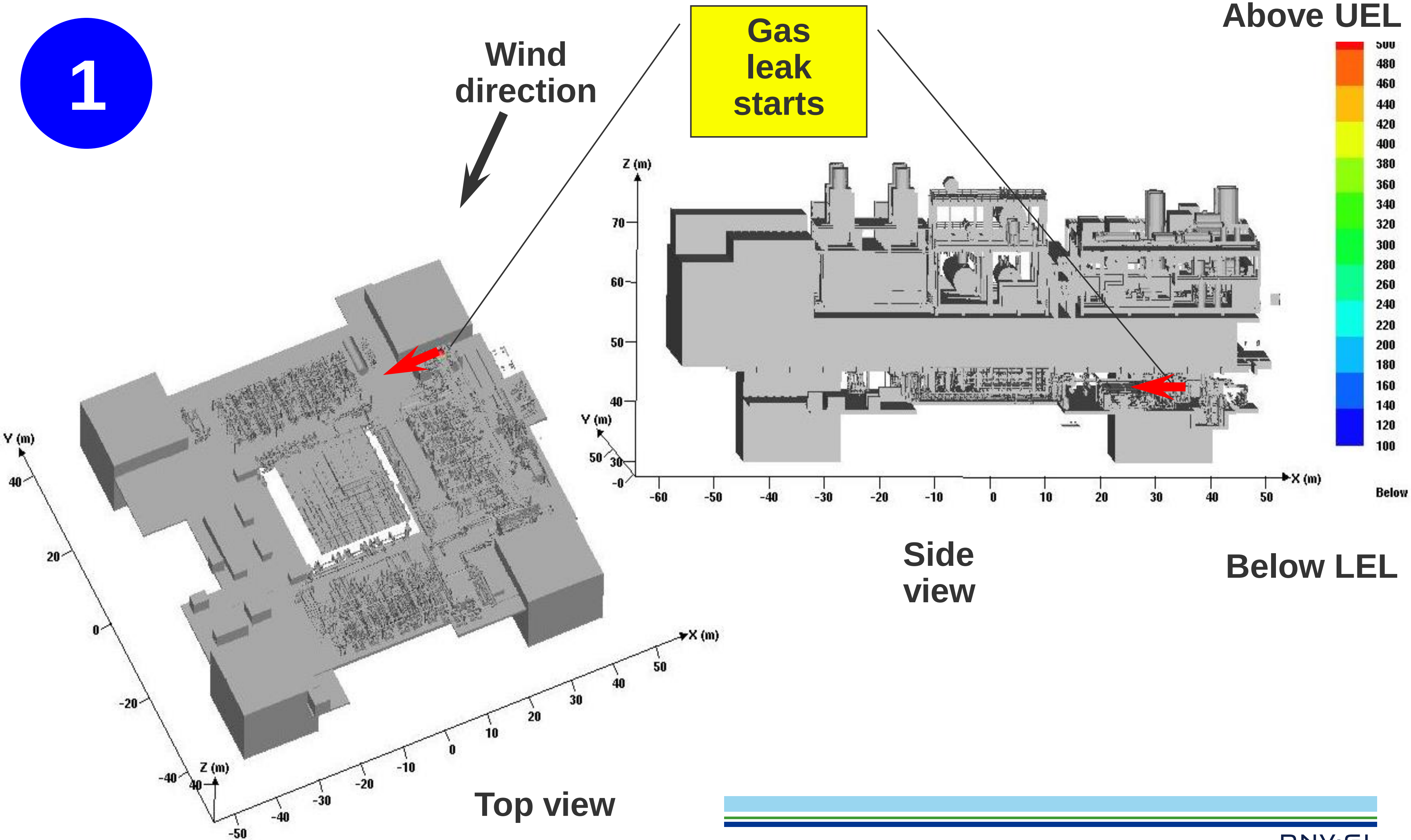
Pressure frequency exceedance curves

Ignition probabilities

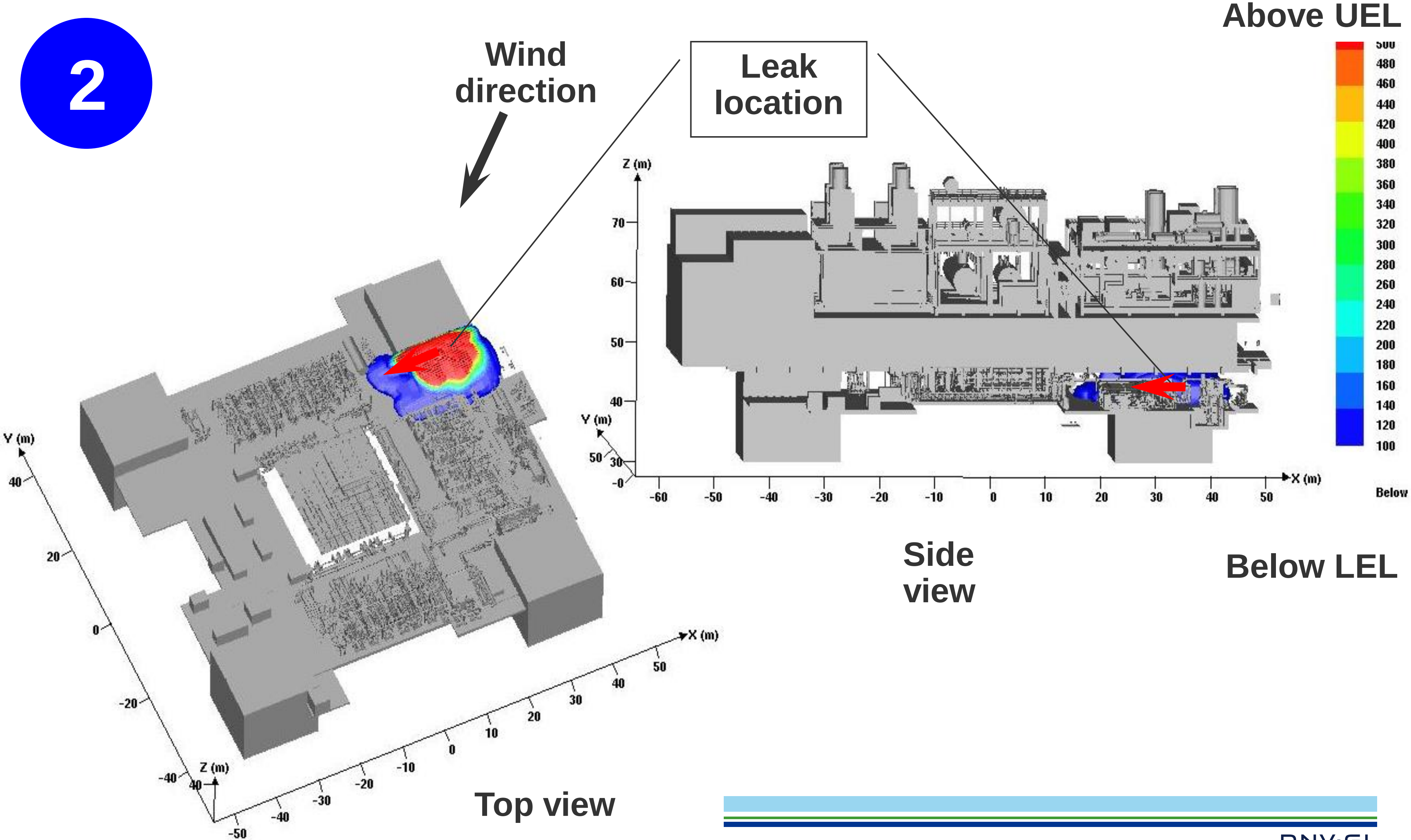
Large semi-sub



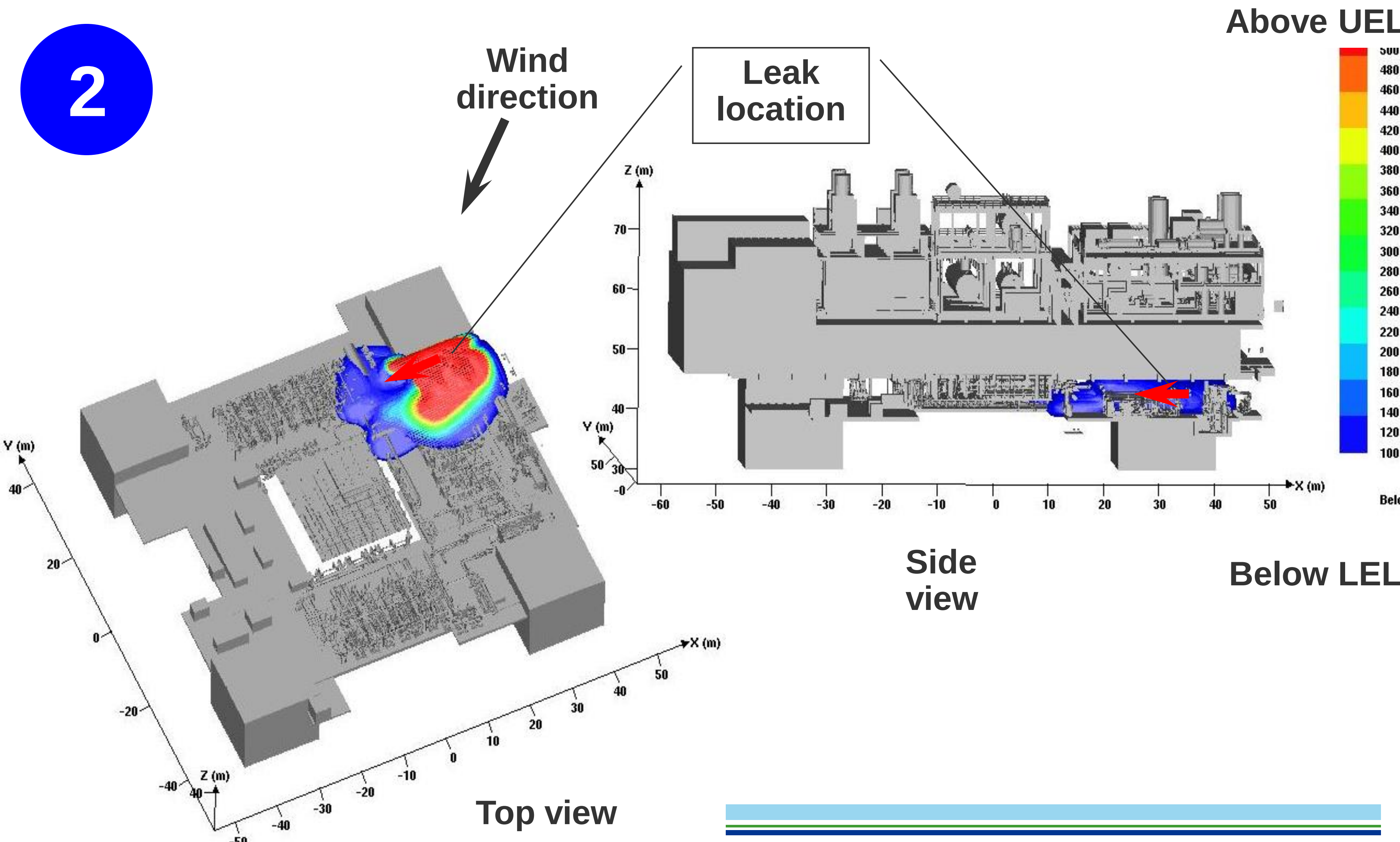
Gas leak starts, *t* = 0 s



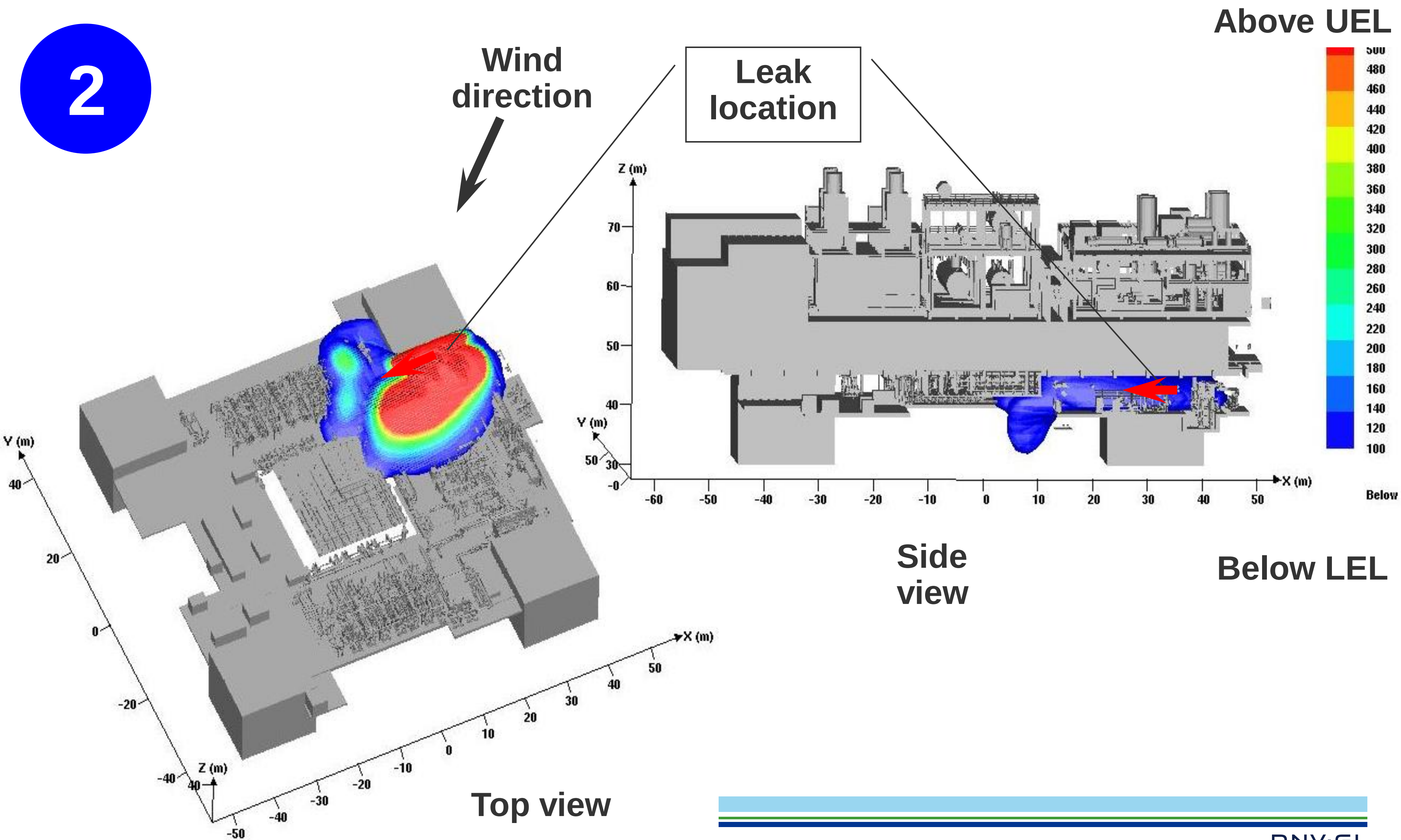
Gas leak dispersion simulation, t = 5 s



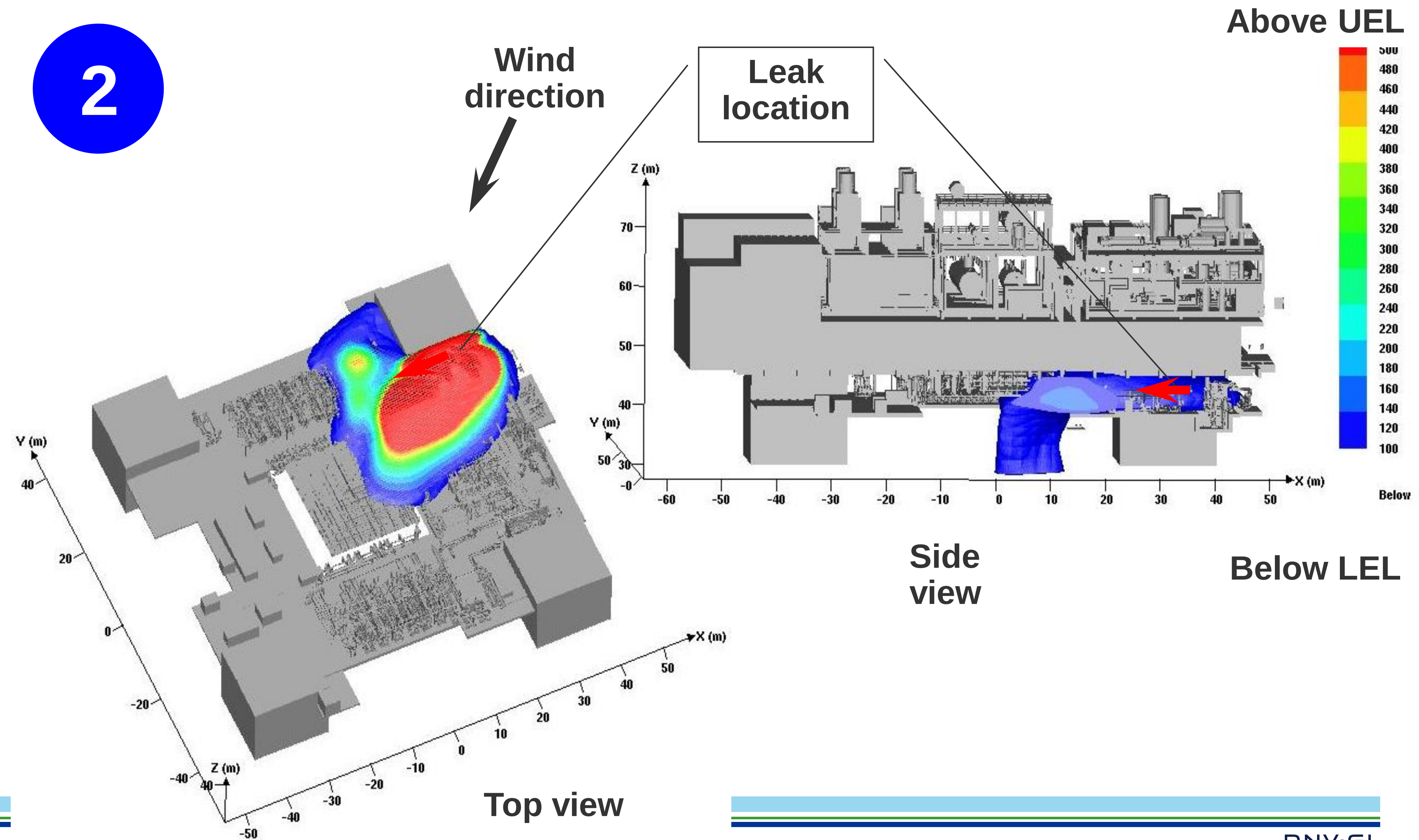
Gas leak dispersion simulation, *t* = 10 s



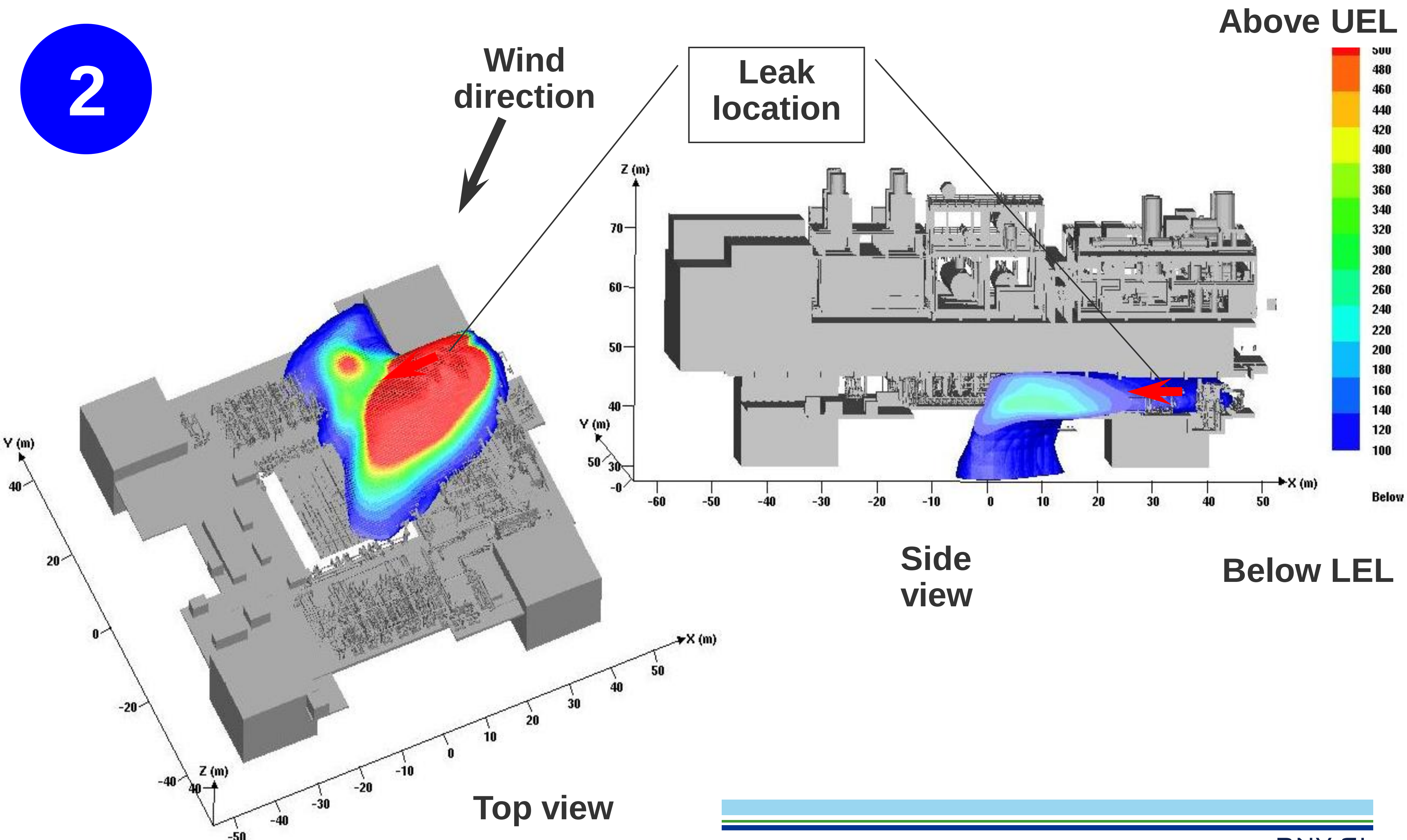
Gas leak dispersion simulation, *t* = 15 s



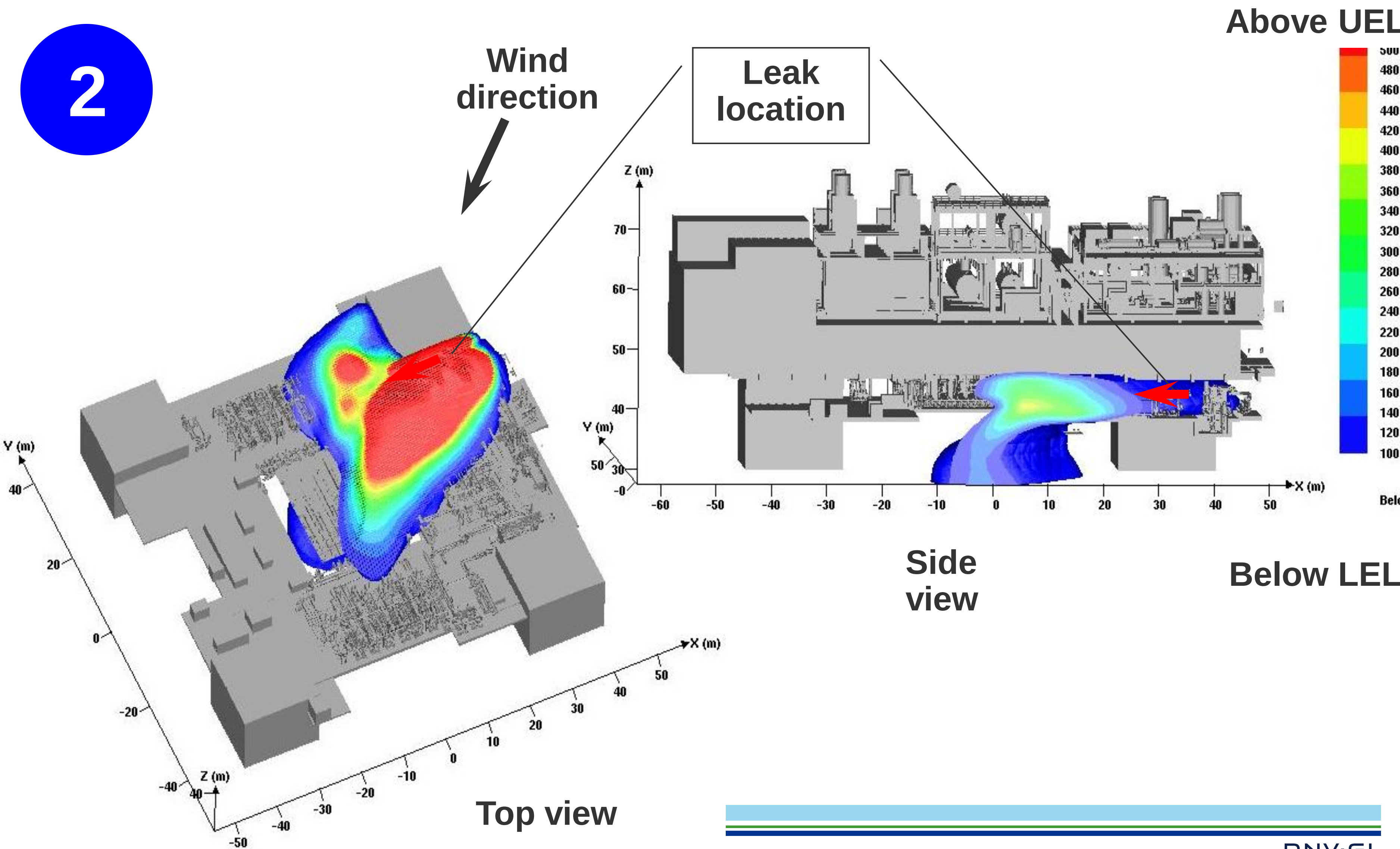
Gas leak dispersion simulation, *t* = 20 s



Gas leak dispersion simulation, *t* = 25 s

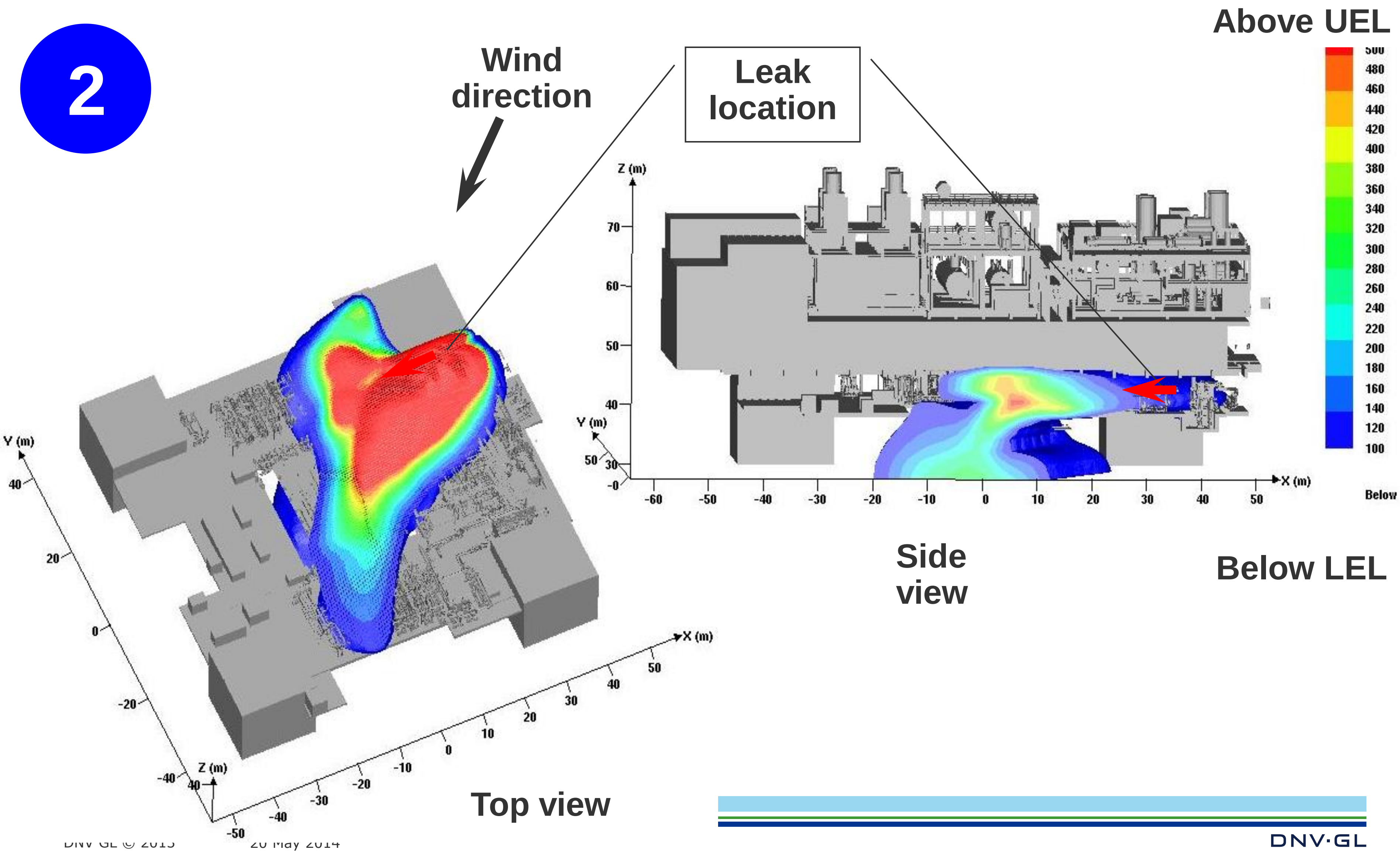


Gas leak dispersion simulation, *t* = 30 s



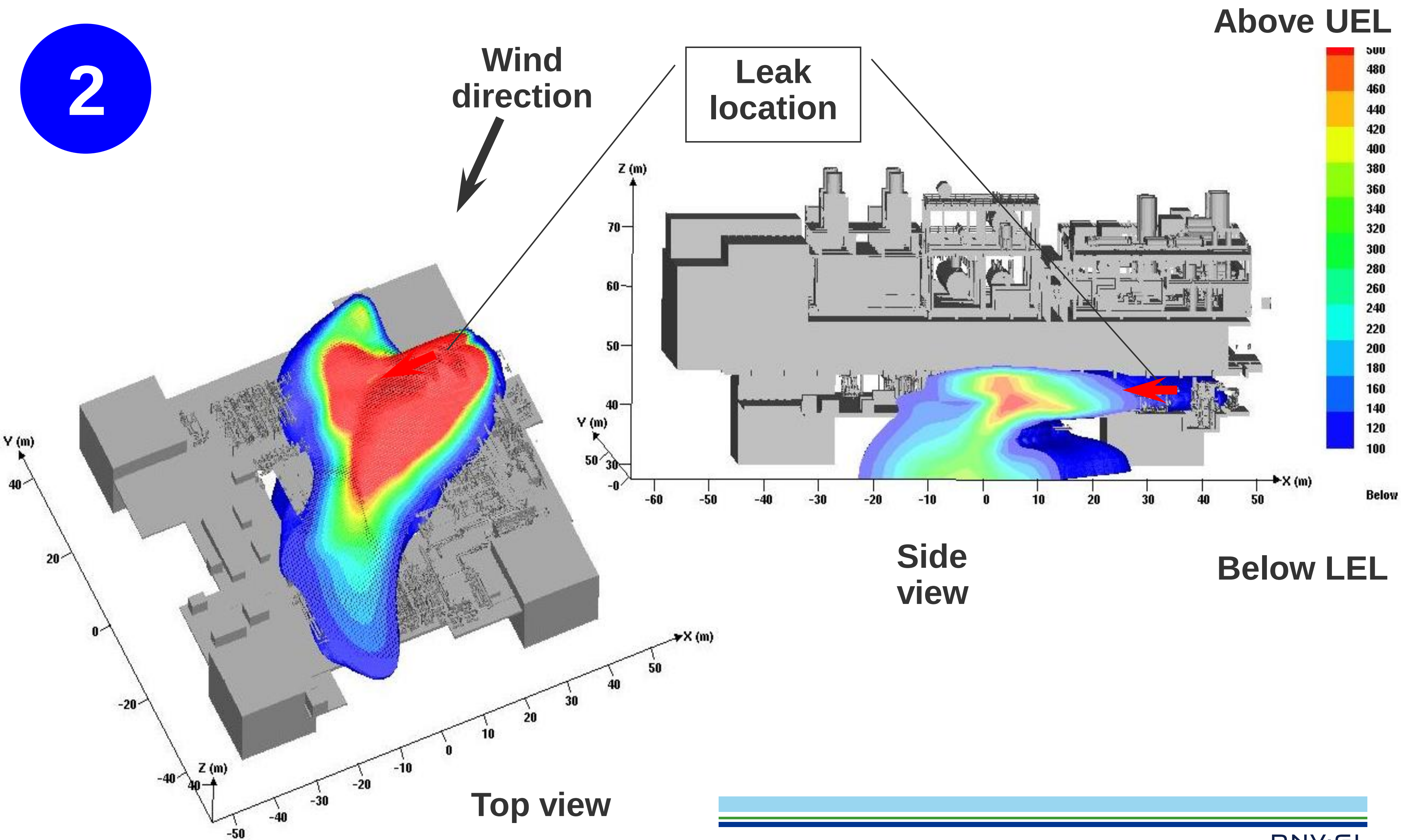
Gas leak dispersion simulation, *t* = 35 s

2



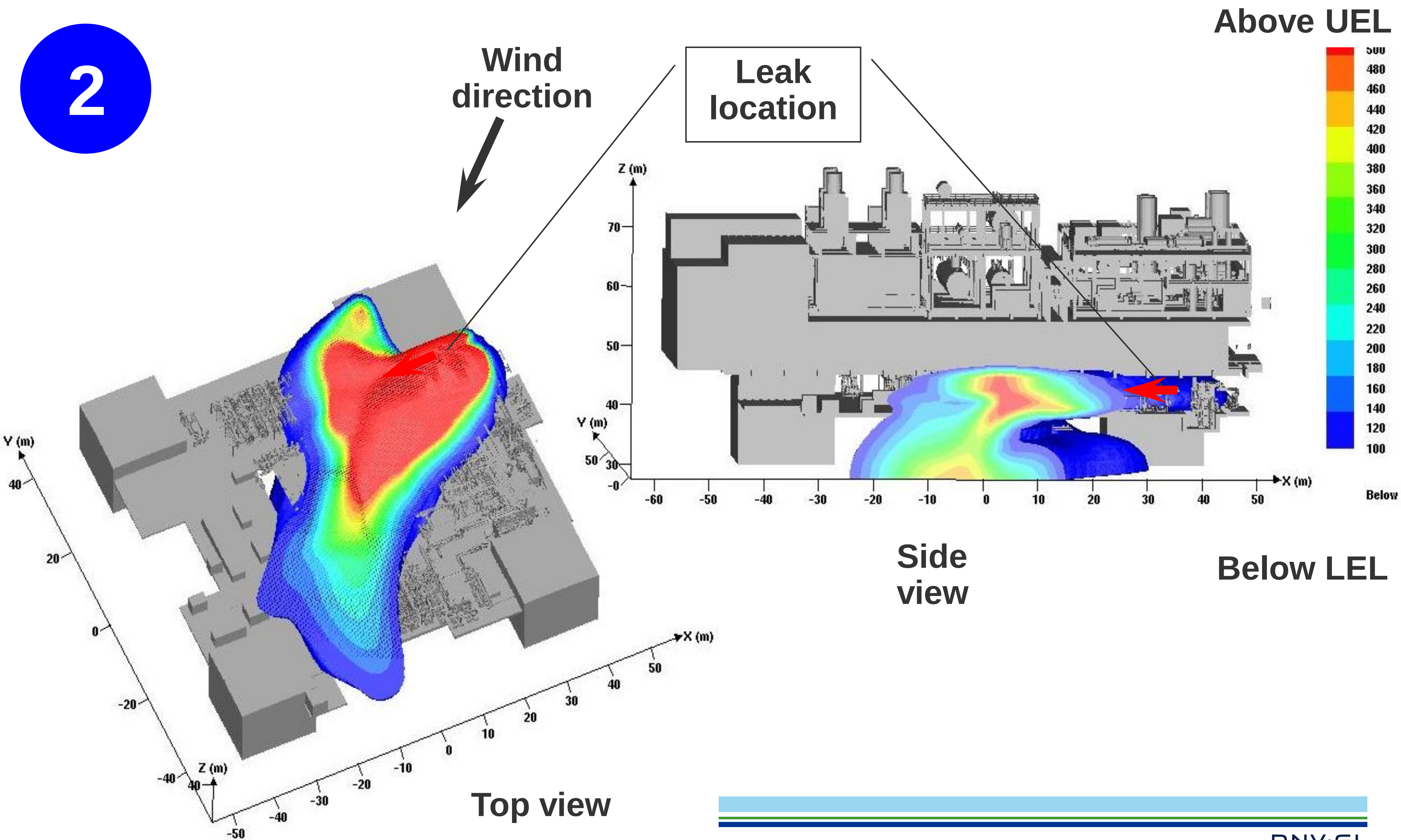
Gas leak dispersion simulation, *t* = 40 s

2

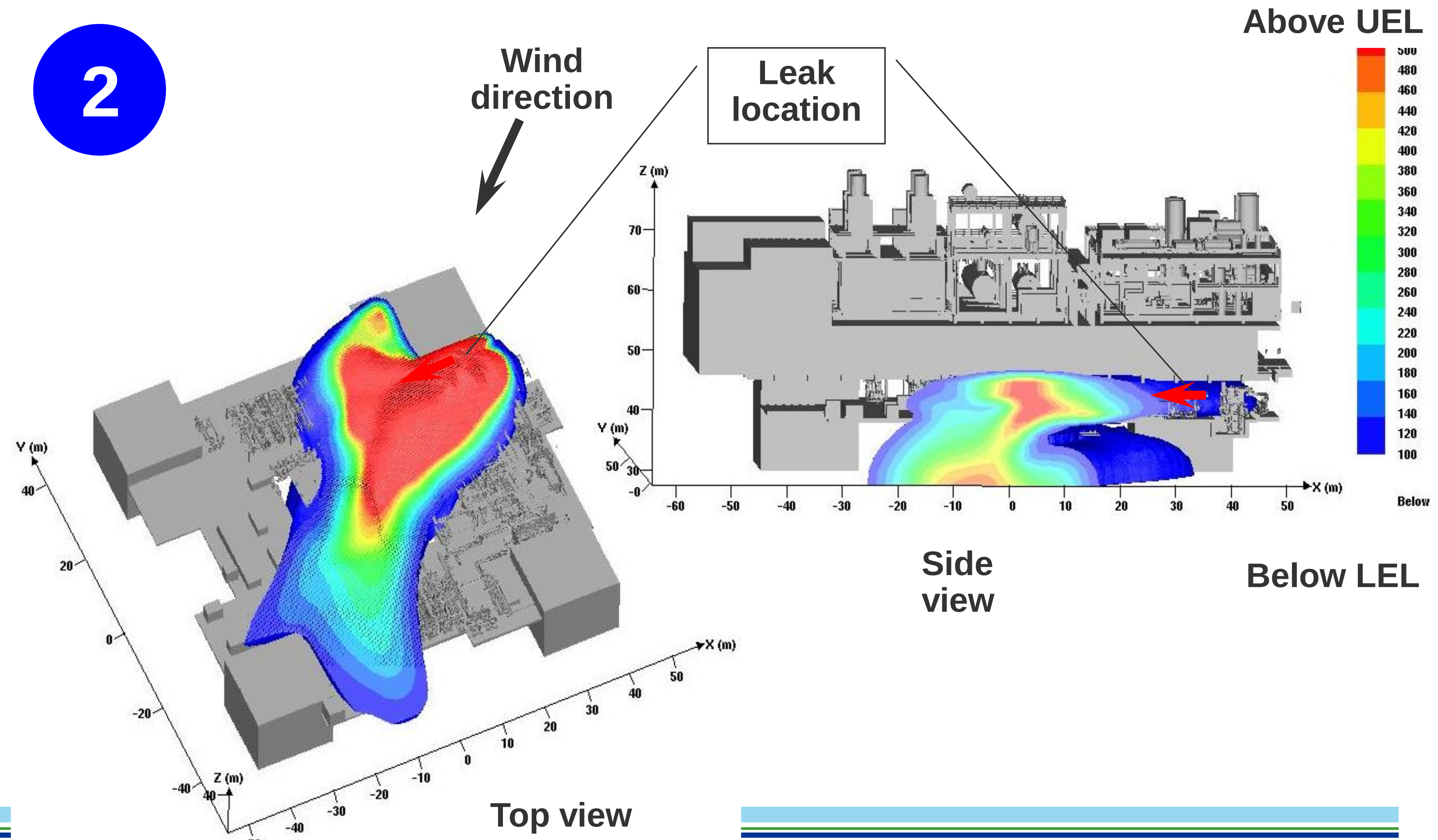


Gas leak dispersion simulation, *t* = 45 s

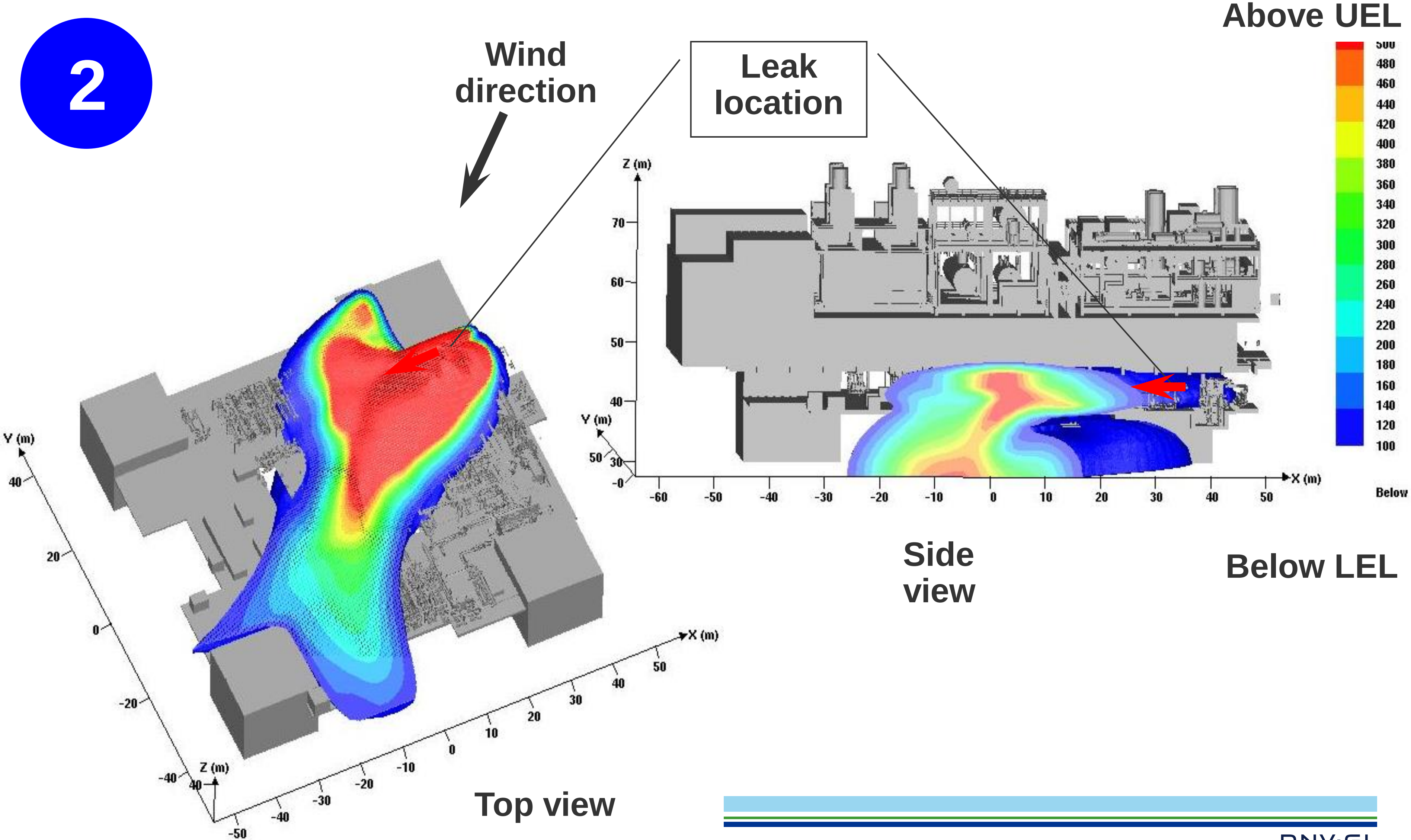
2



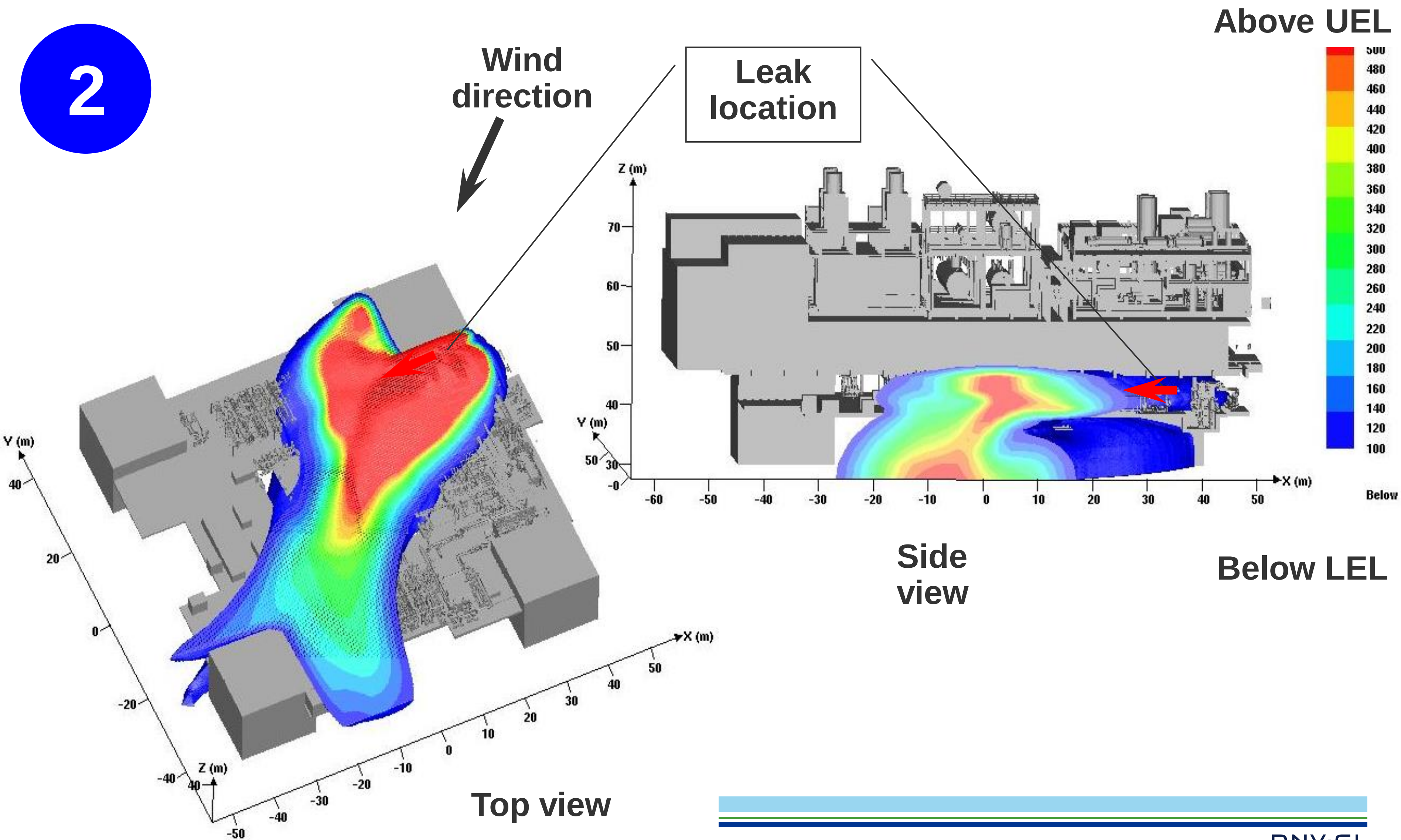
Gas leak dispersion simulation, *t* = 50 s



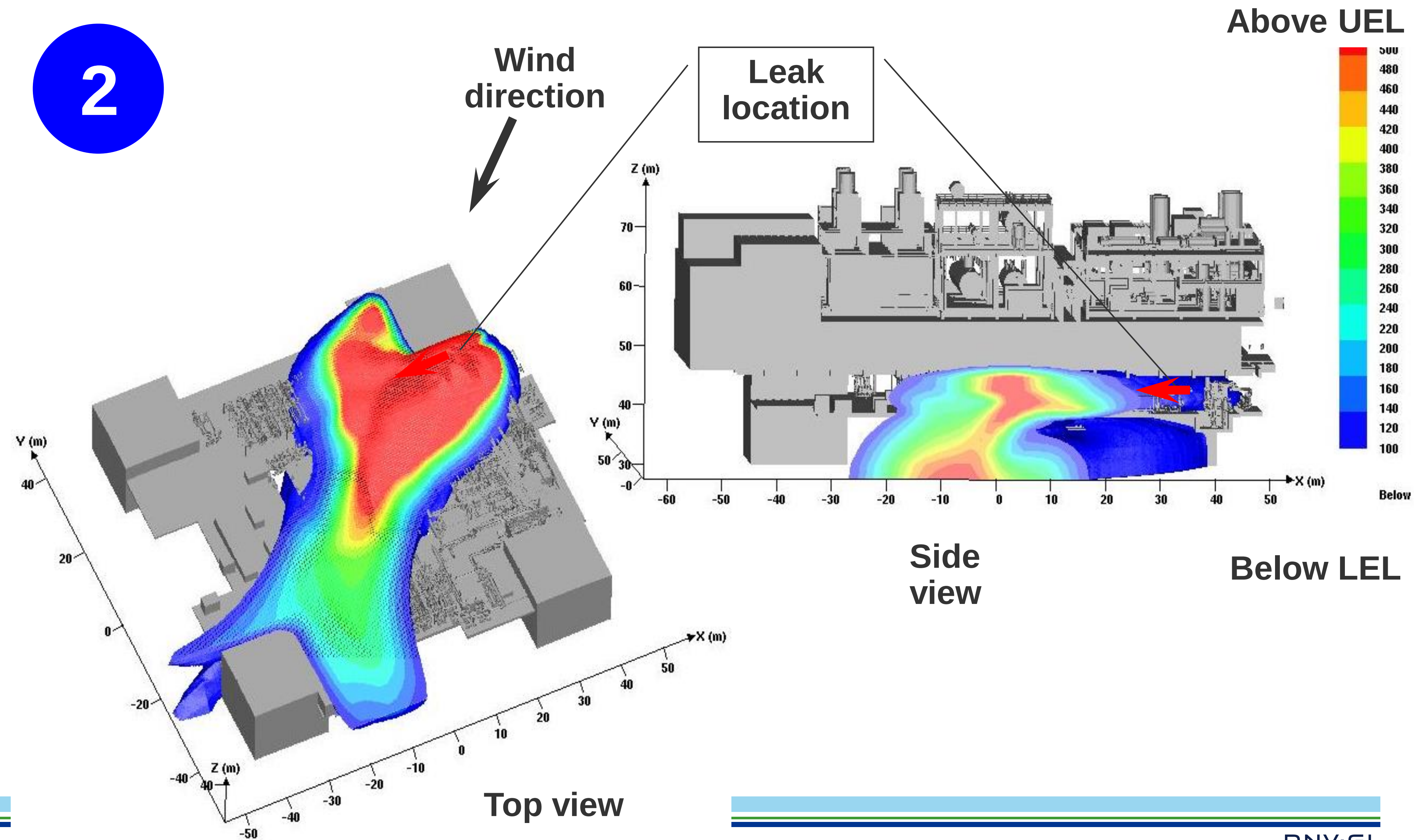
Gas leak dispersion simulation, *t* = 55 s



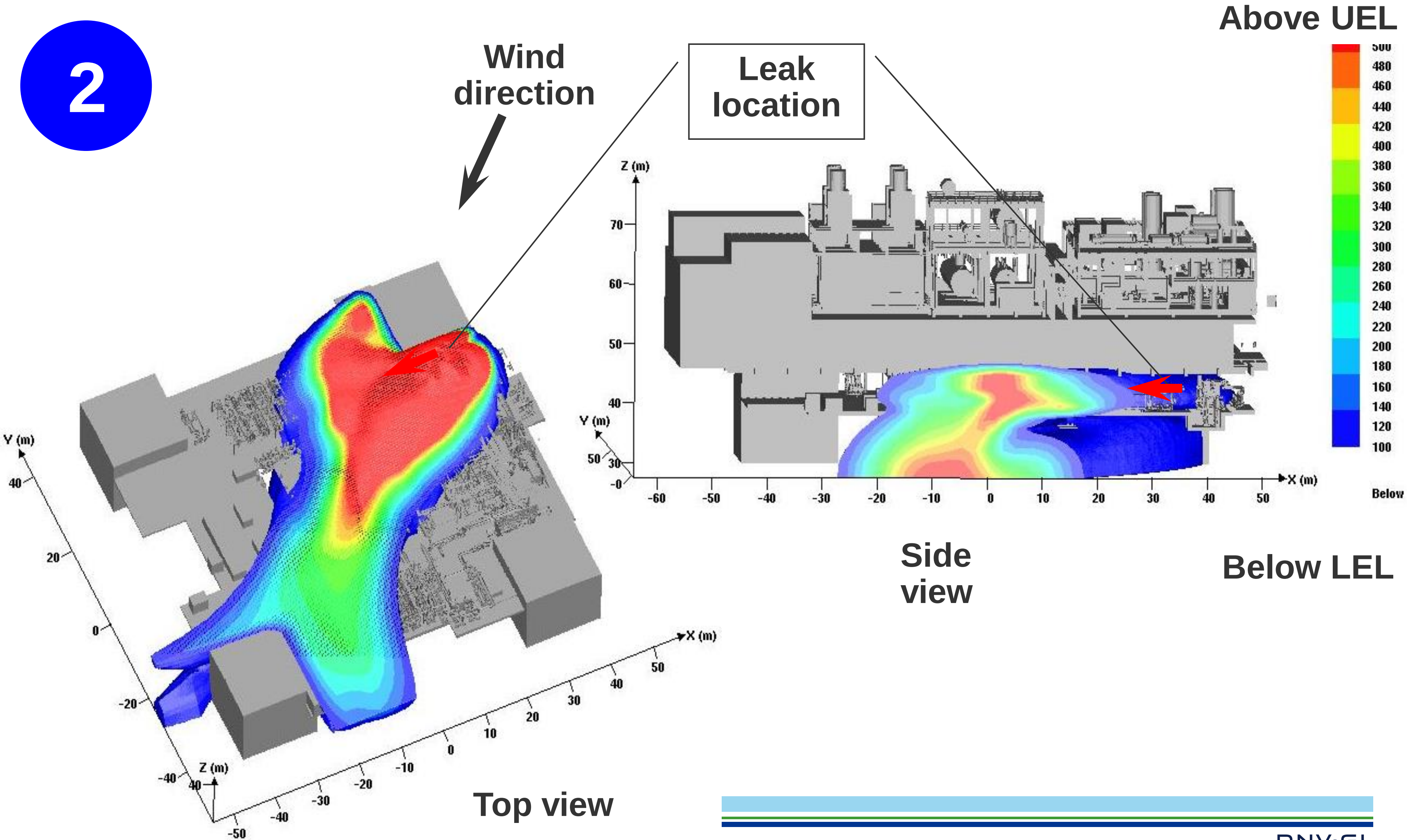
Gas leak dispersion simulation, *t* = 60 s



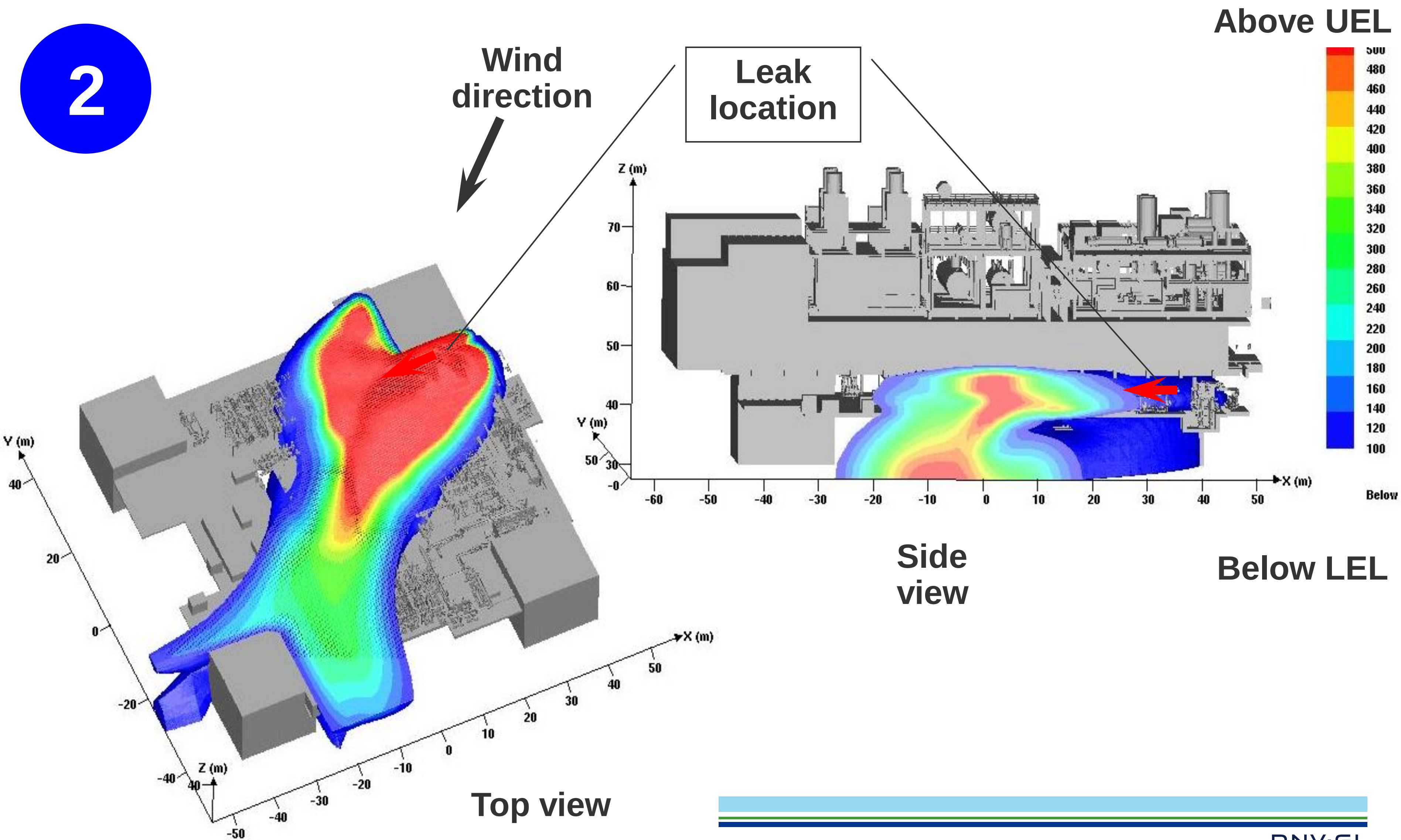
Gas leak dispersion simulation, *t* = 65 s



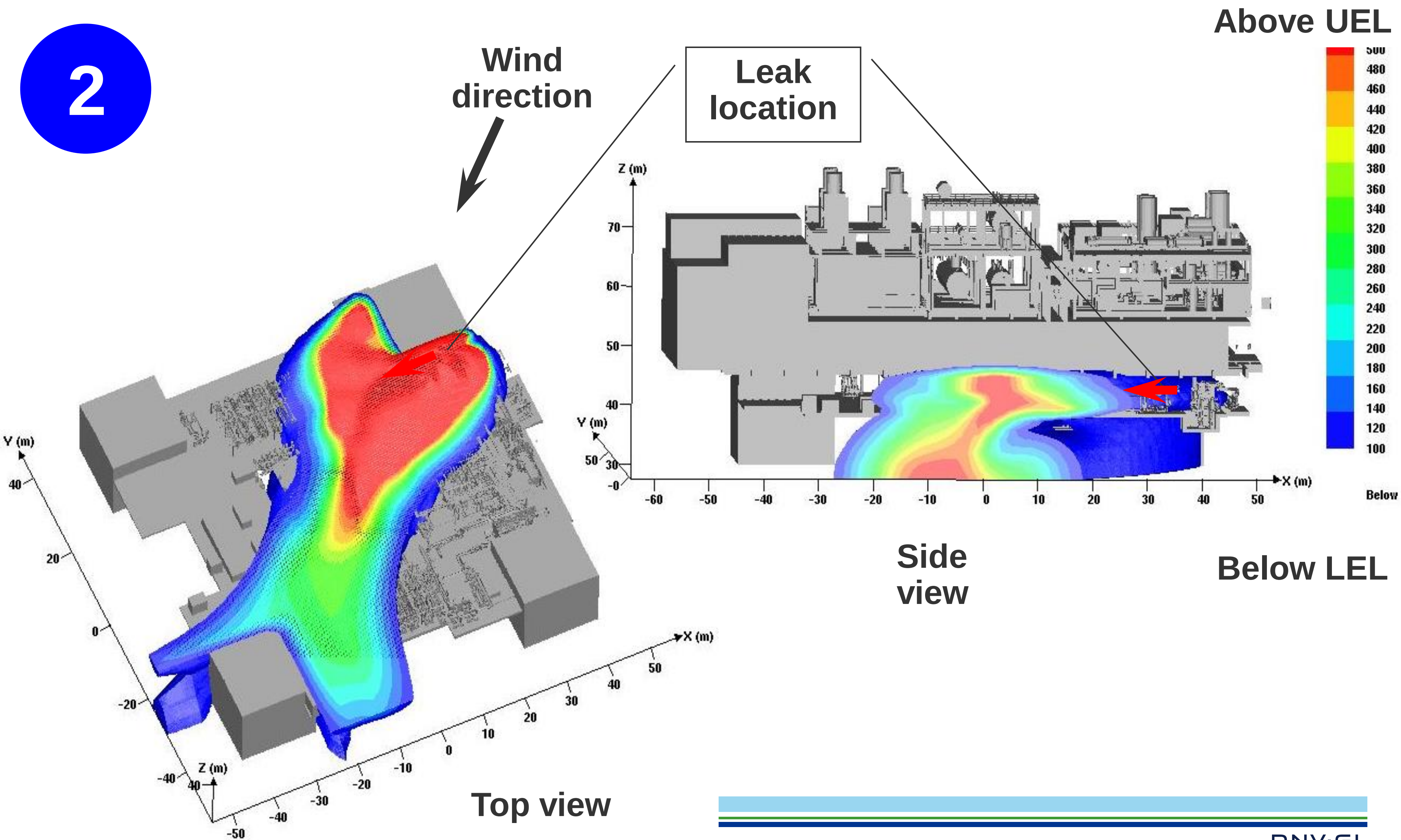
Gas leak dispersion simulation, *t* = 70 s



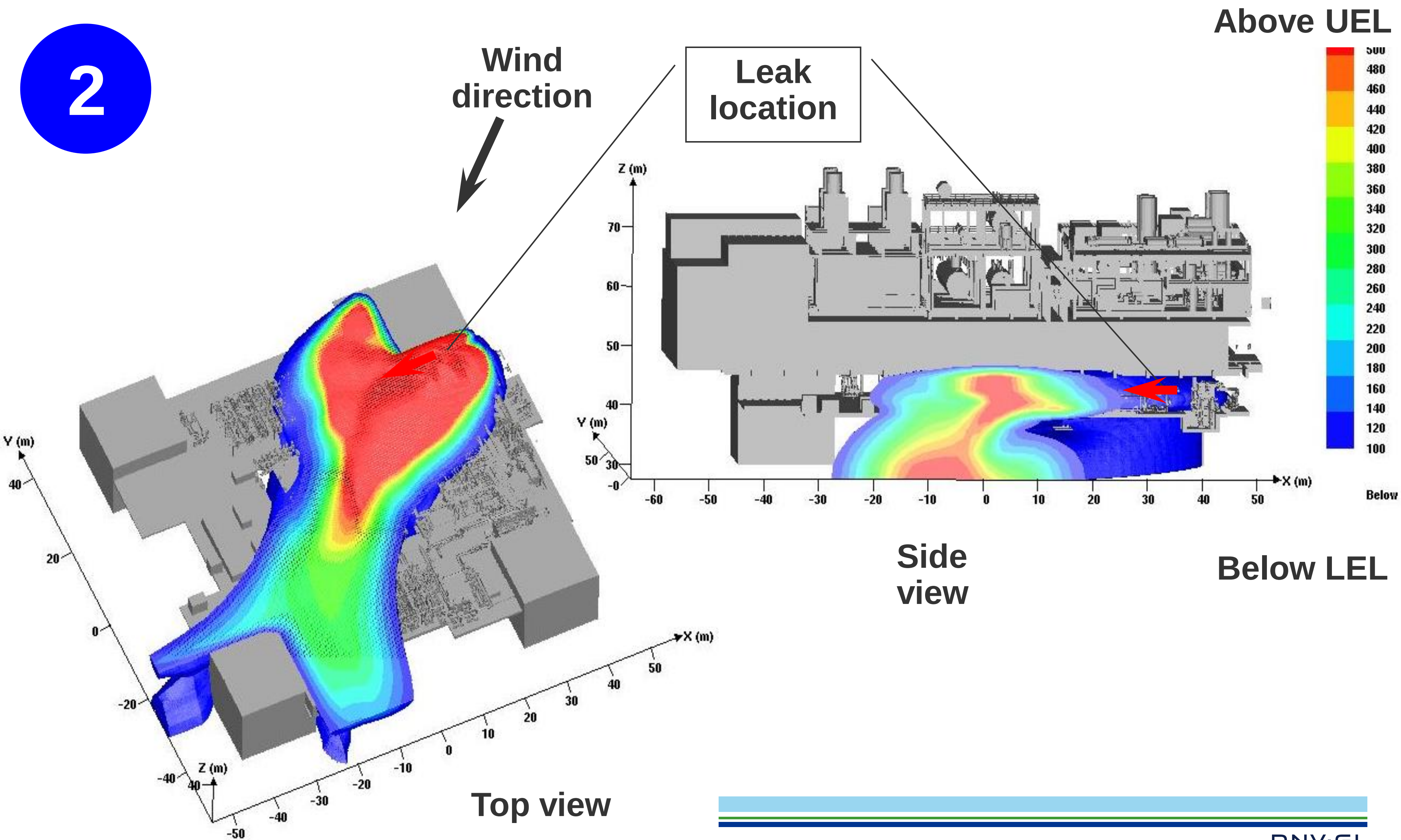
Gas leak dispersion simulation, *t* = 75 s



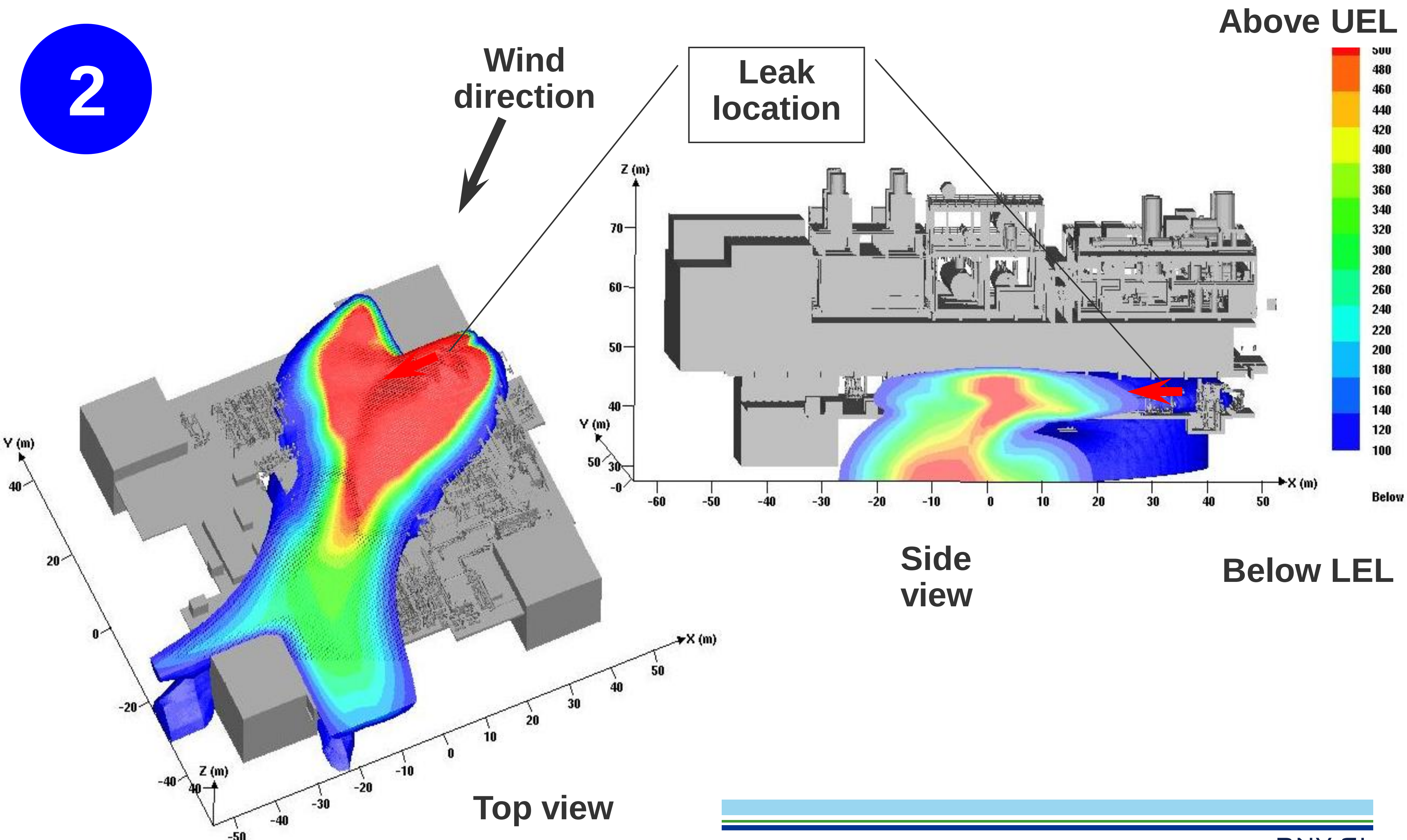
Gas leak dispersion simulation, *t* = 80 s



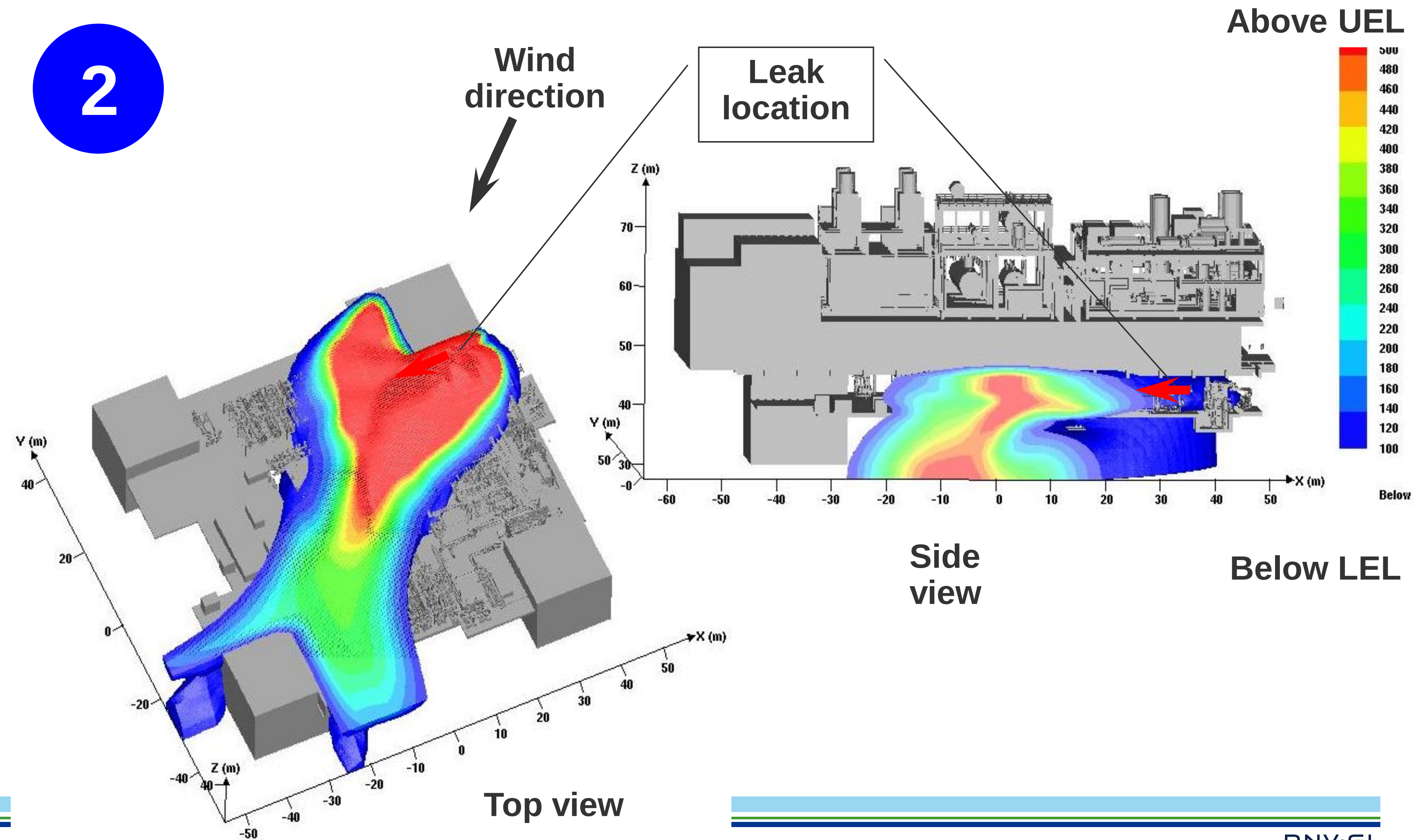
Gas leak dispersion simulation, *t* = 85 s



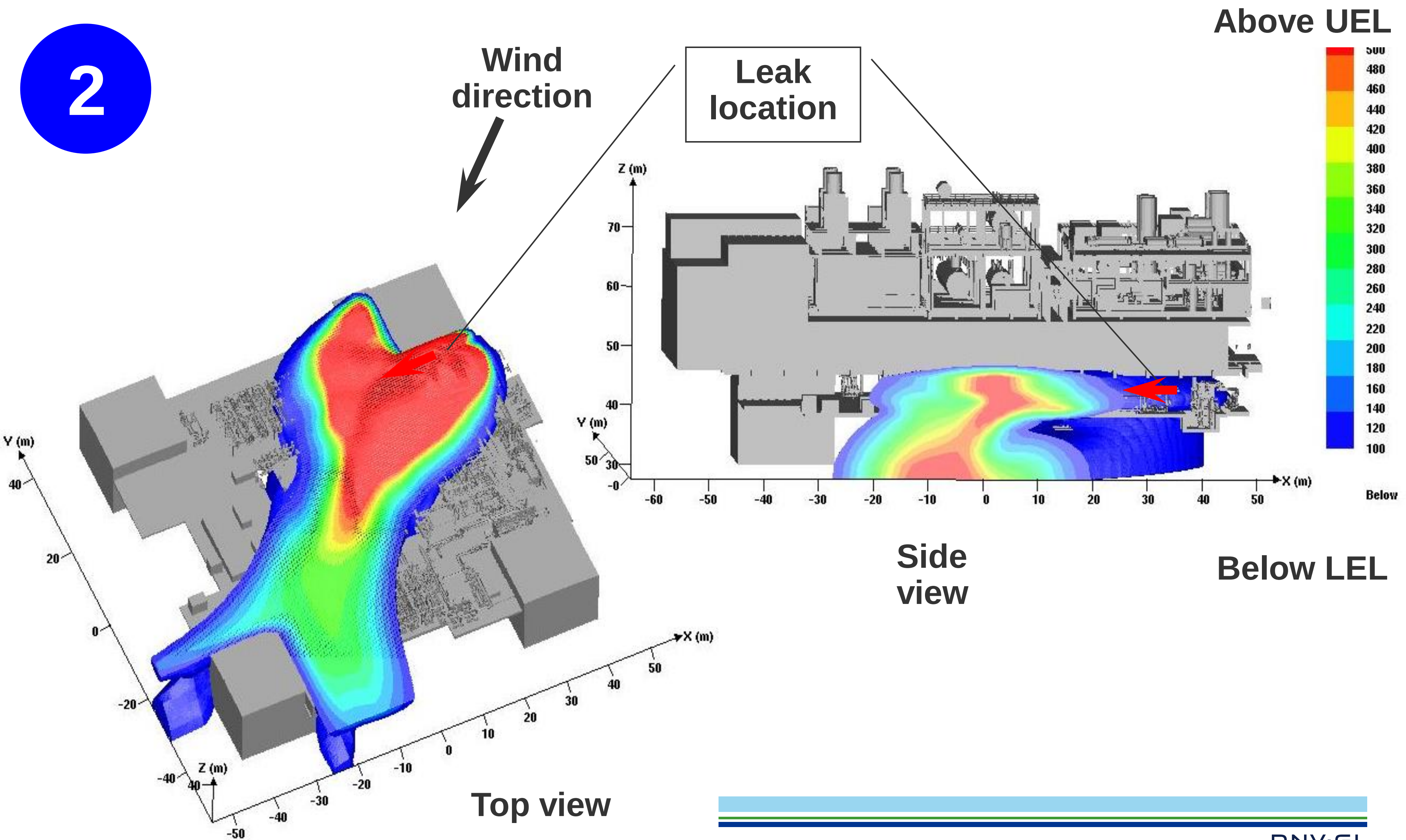
Gas leak dispersion simulation, t = 90 s



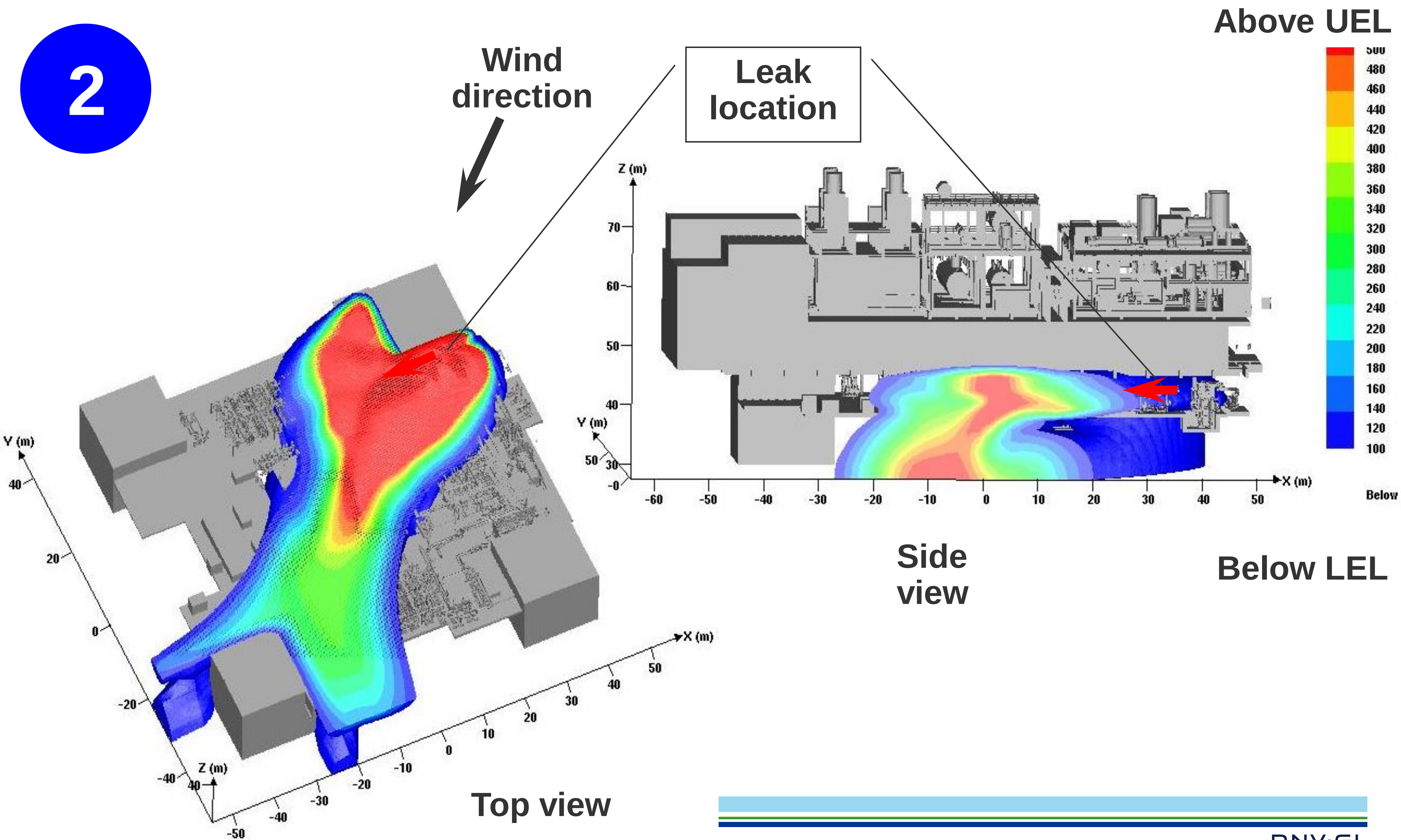
Gas leak dispersion simulation, *t* = 95 s



Gas leak dispersion simulation, *t* = 100 s



Gas leak dispersion simulation, *t* = 105 s

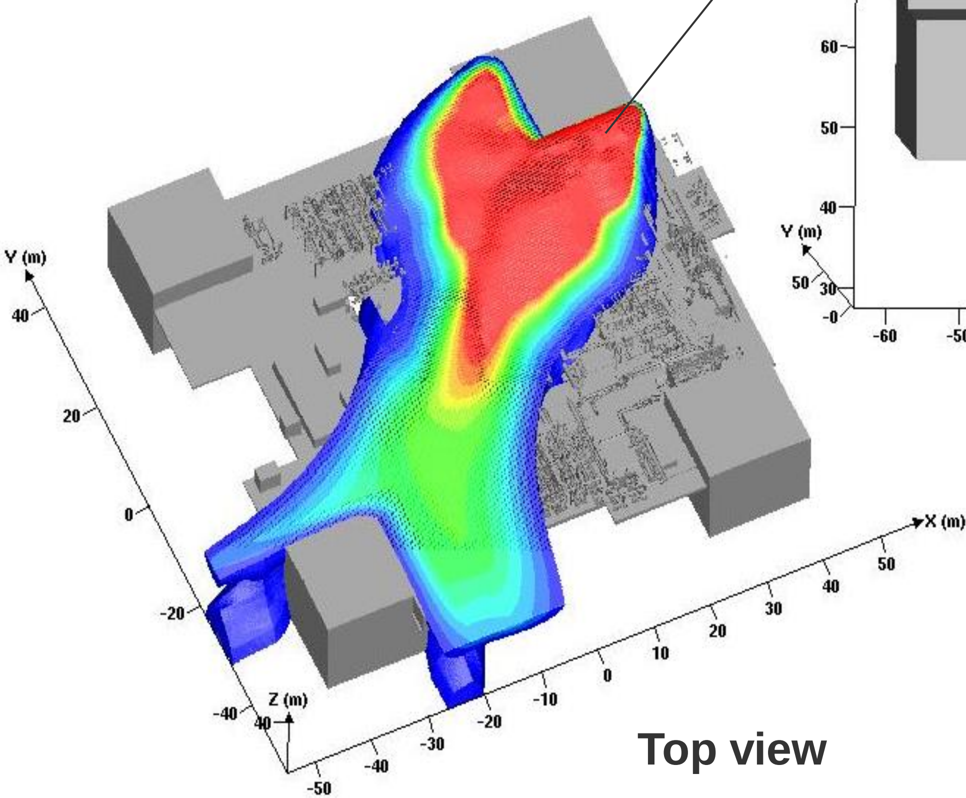


Gas leak dispersion simulation, *t* = 110 s

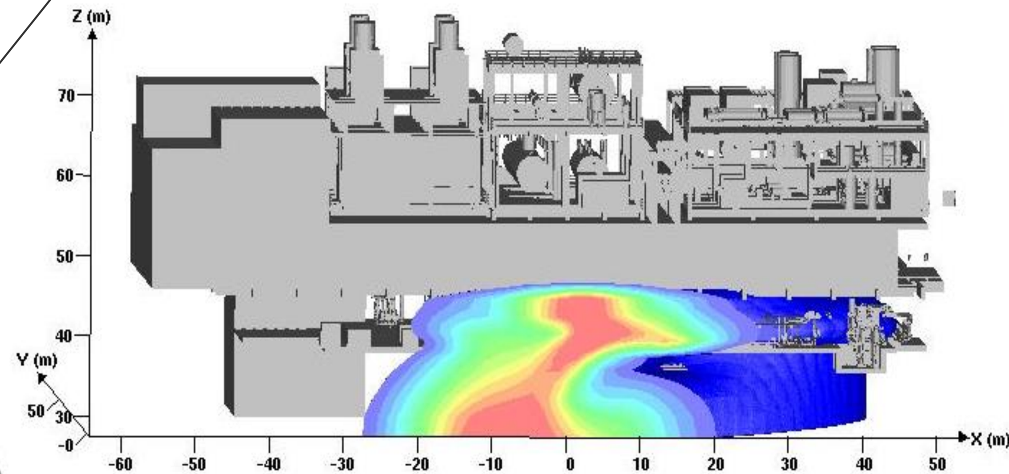
2

Wind direction

Leak ends

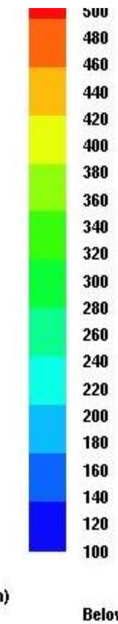


Top view



Side view

Above UEL

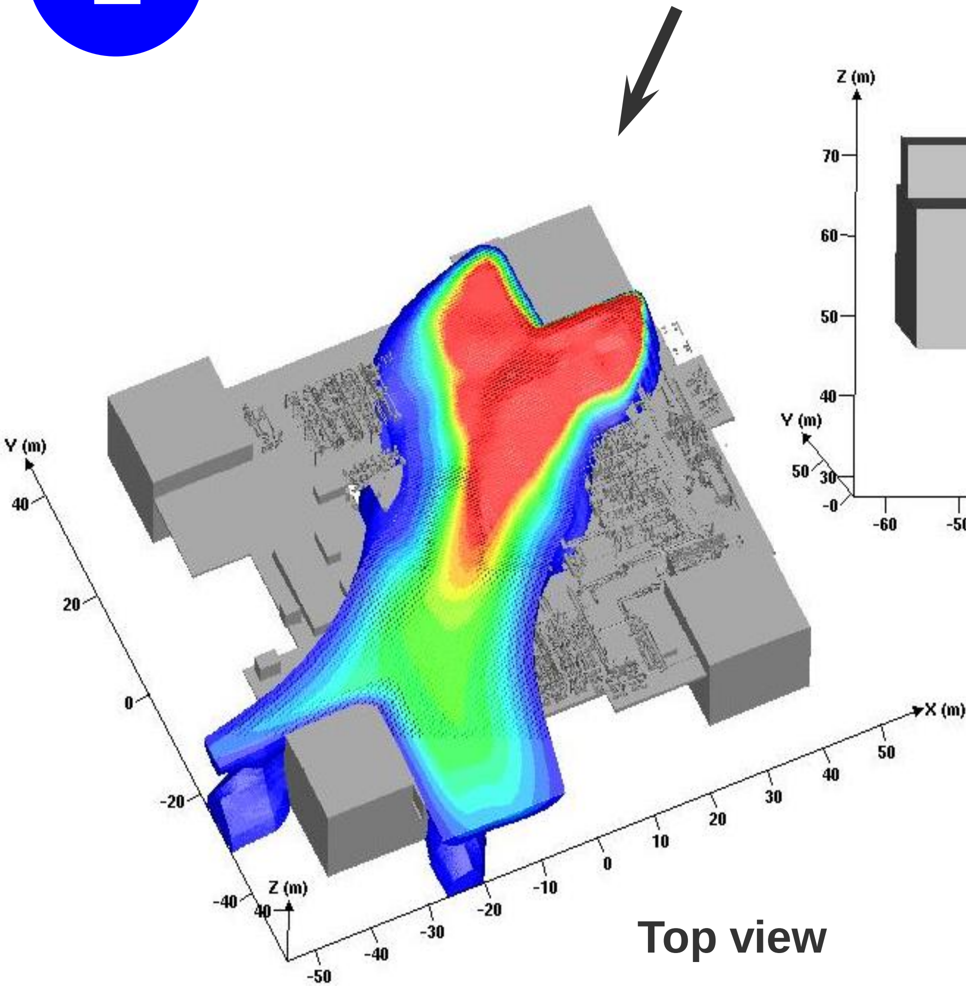


Below LEL

Gas leak dispersion simulation, t = 115 s

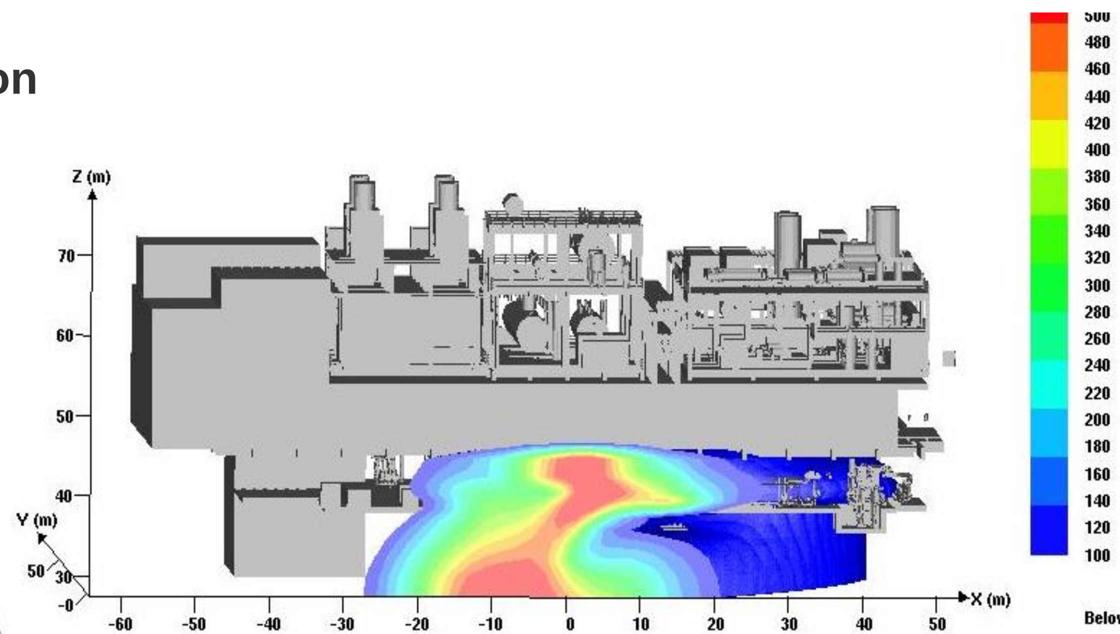
2

Wind direction



Top view

Above UEL



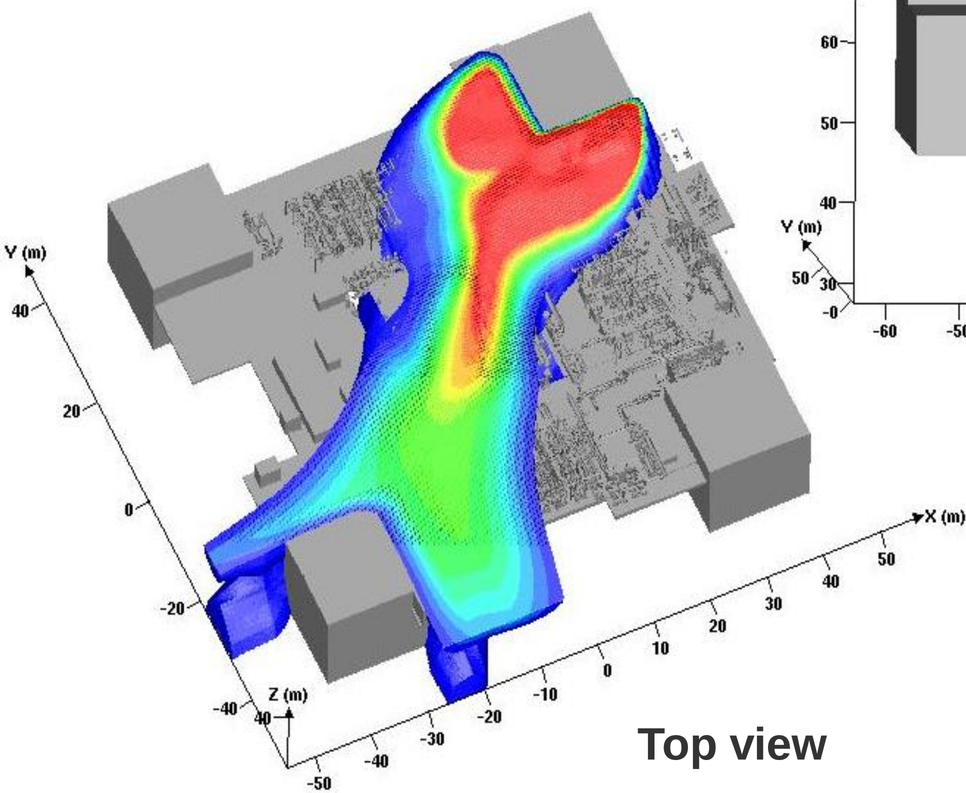
Side view

Below LEL

Gas leak dispersion simulation, t = 120 s

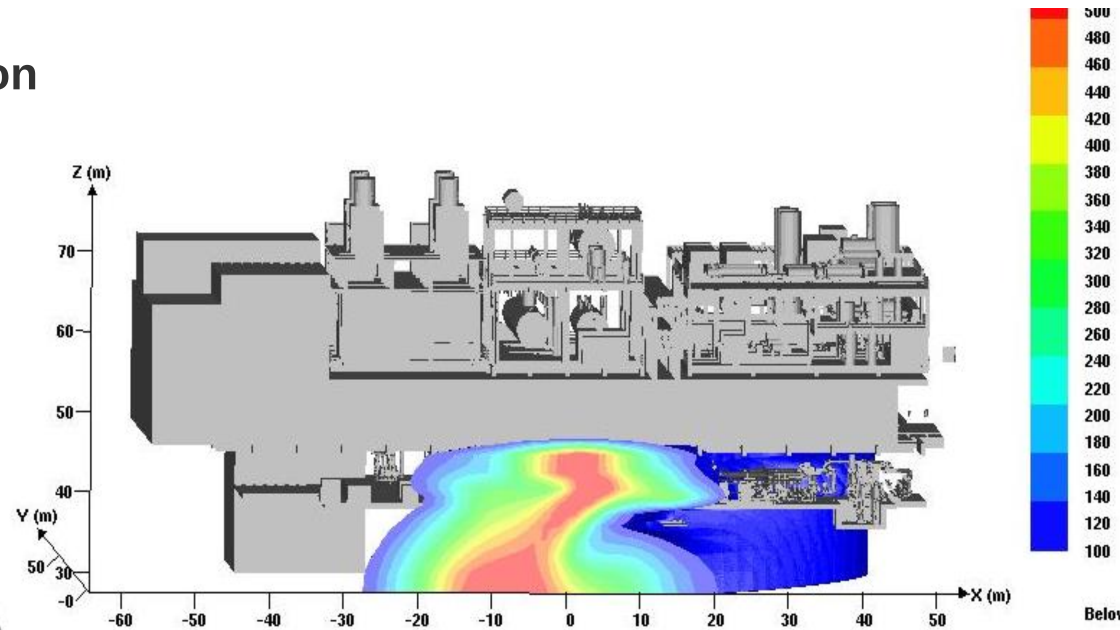
2

Wind direction



Top view

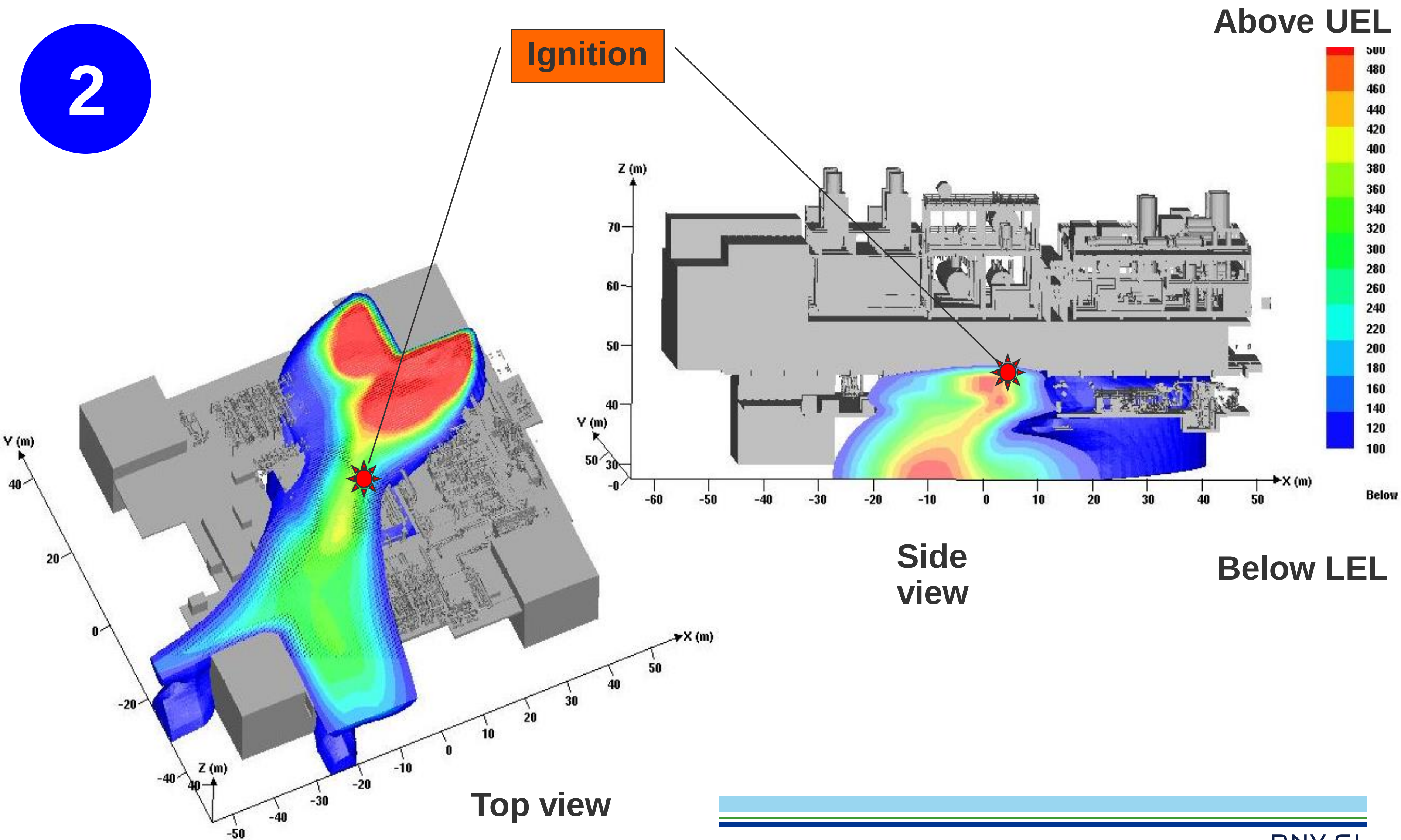
Above UEL



Side view

Below LEL

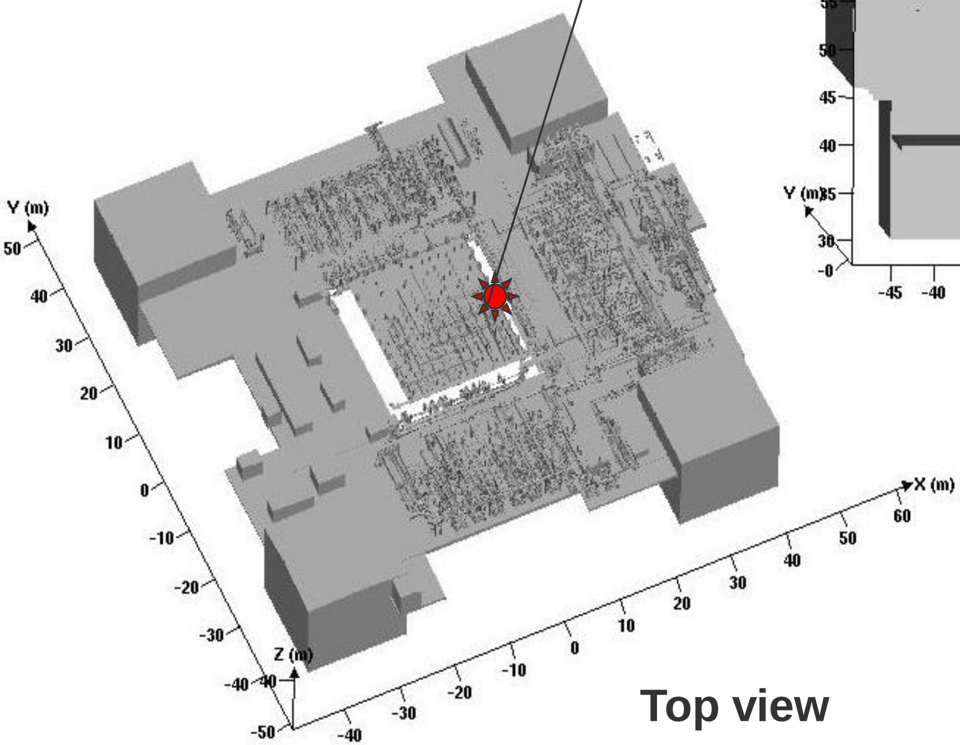
Gas leak dispersion simulation, *t* = 125 s



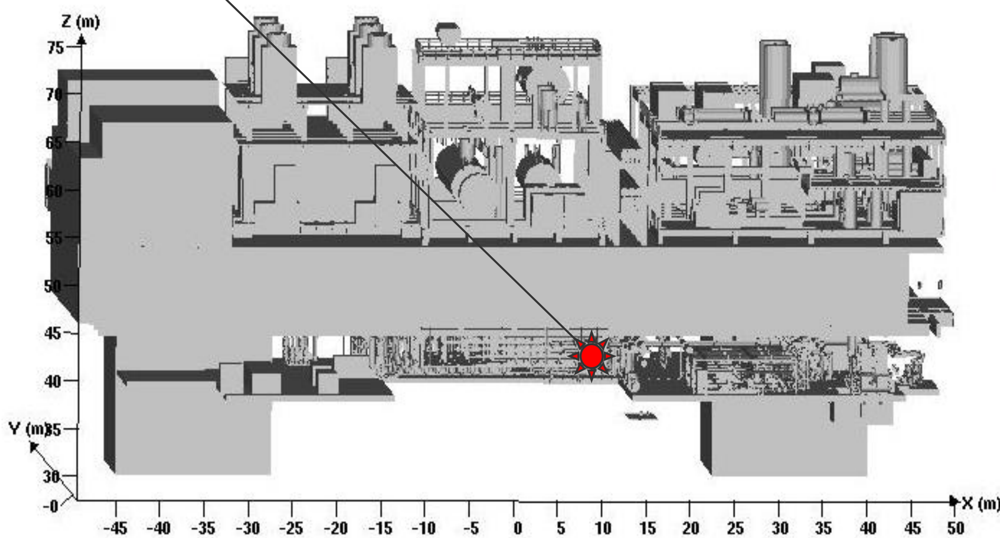
Explosion pressure wave starts - *t* = 0 s

2

Ignition

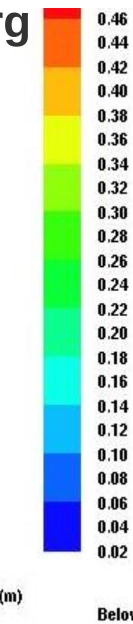


Top view



Side view

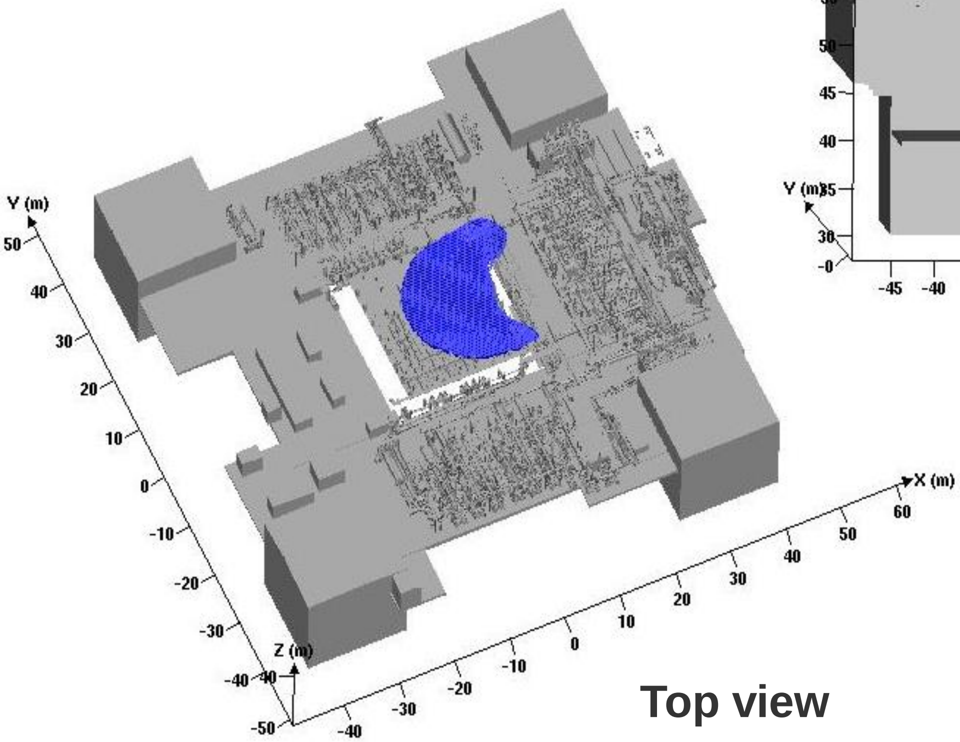
Above 0.5 barg



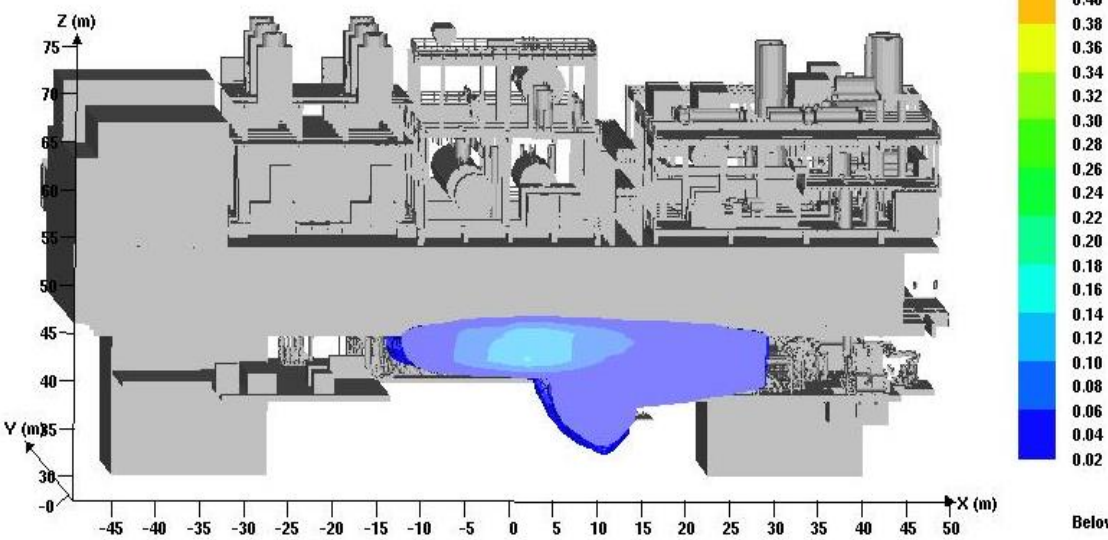
0 barg

Explosion pressure wave starts - t = 1.15 s

2



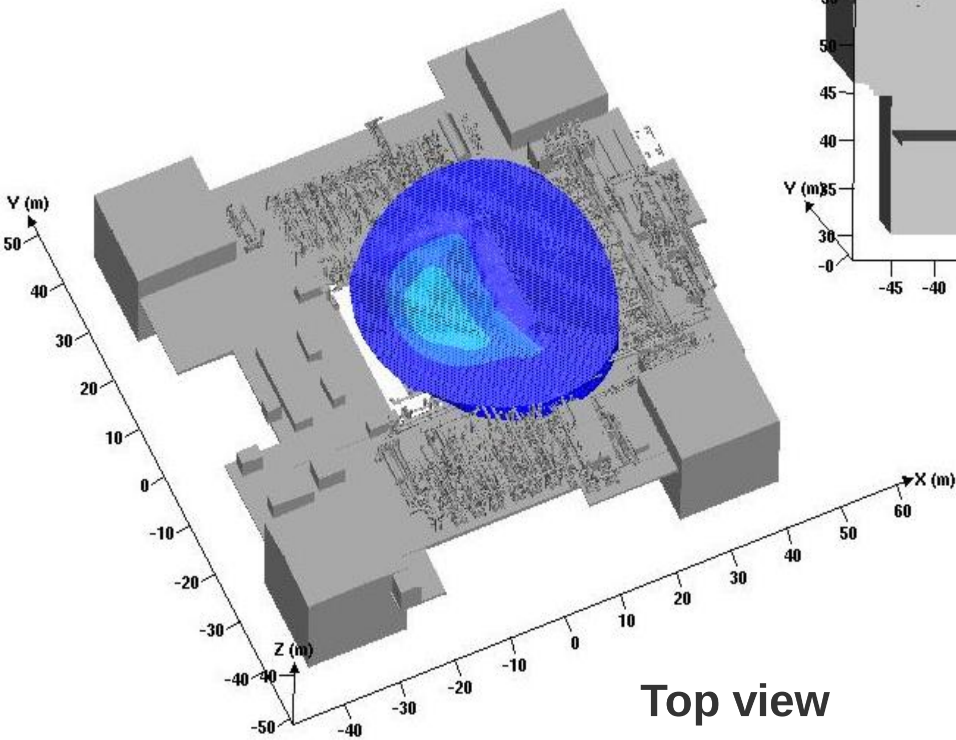
Top view



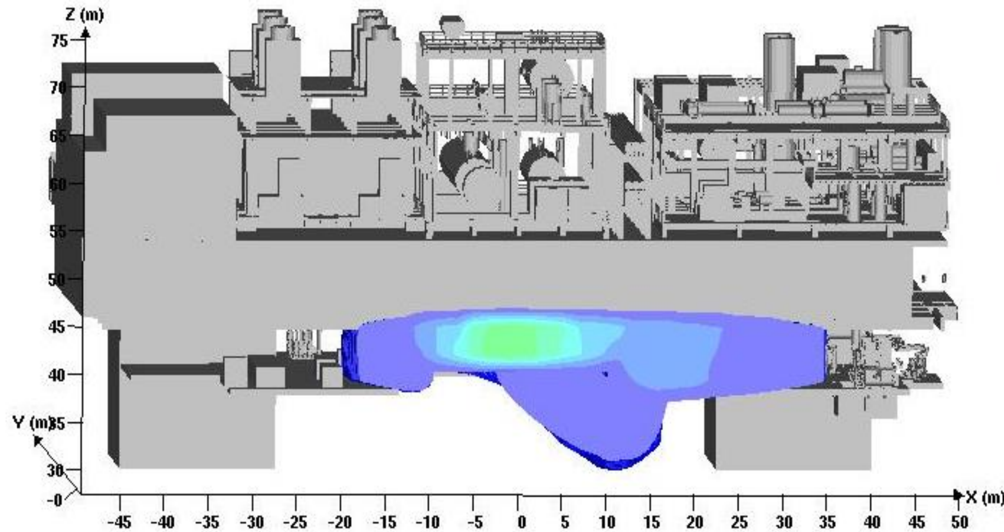
Side view

Explosion pressure wave, *t* = 1.2 s

2

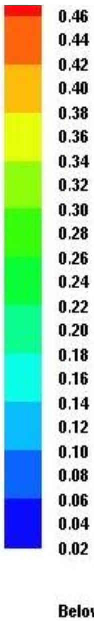


Top view



Side view

Above 0.5 barg

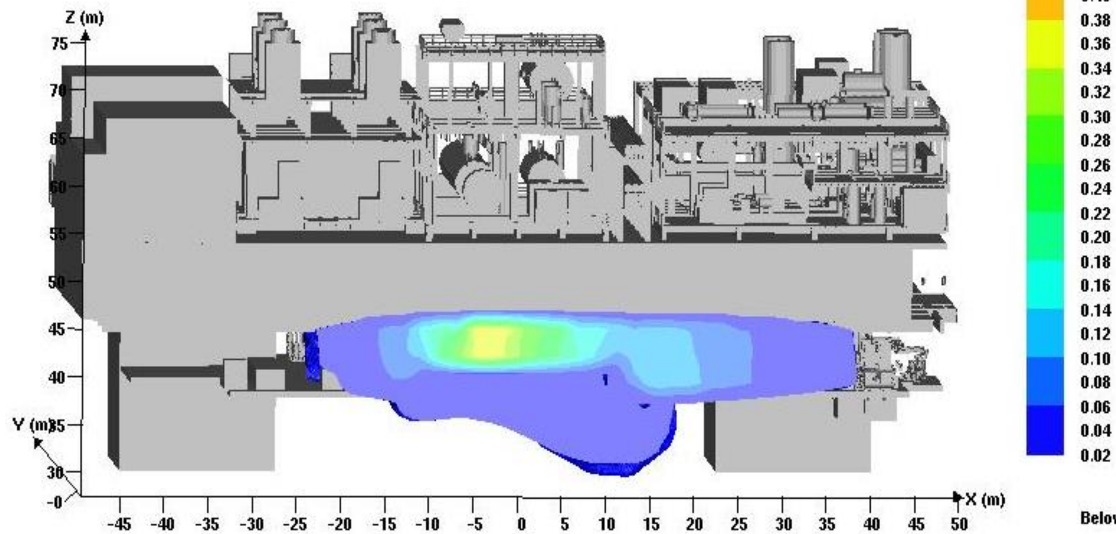


0 barg

Explosion pressure wave, *t* = 1.22 s

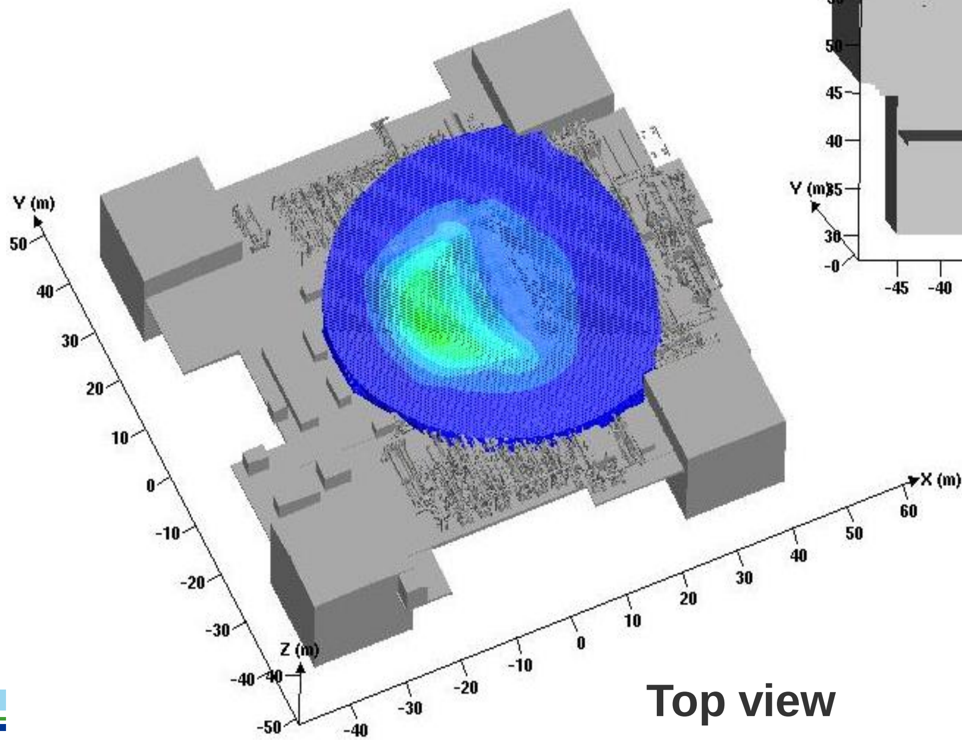
2

Above 0.5 barg



0 barg

Side view

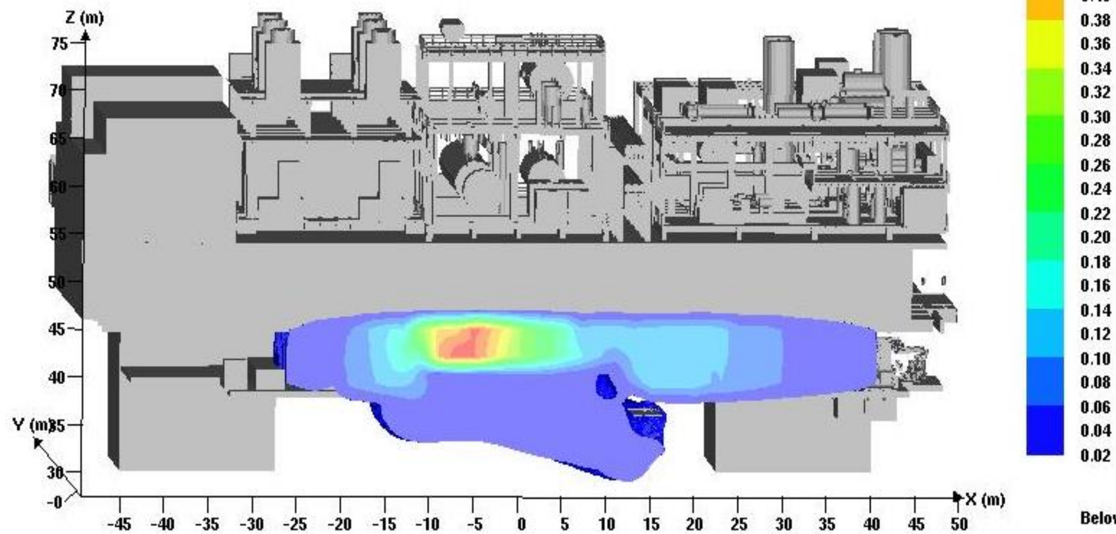


Top view

Explosion pressure wave, *t* = 1.23 s

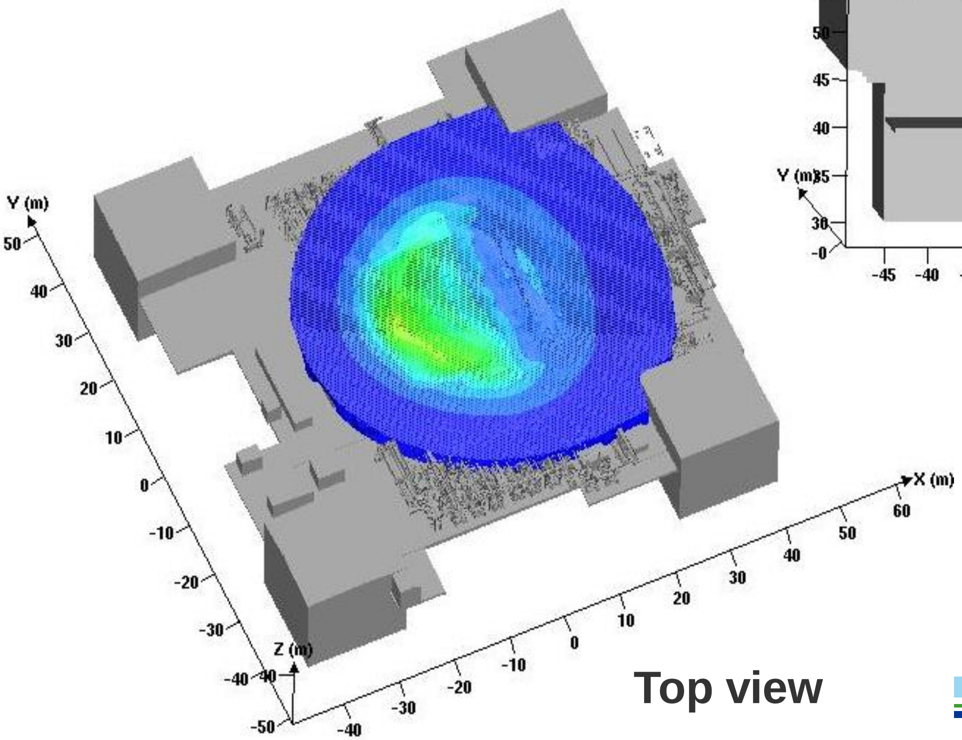
2

Above 0.5 barg



0 barg

Side view

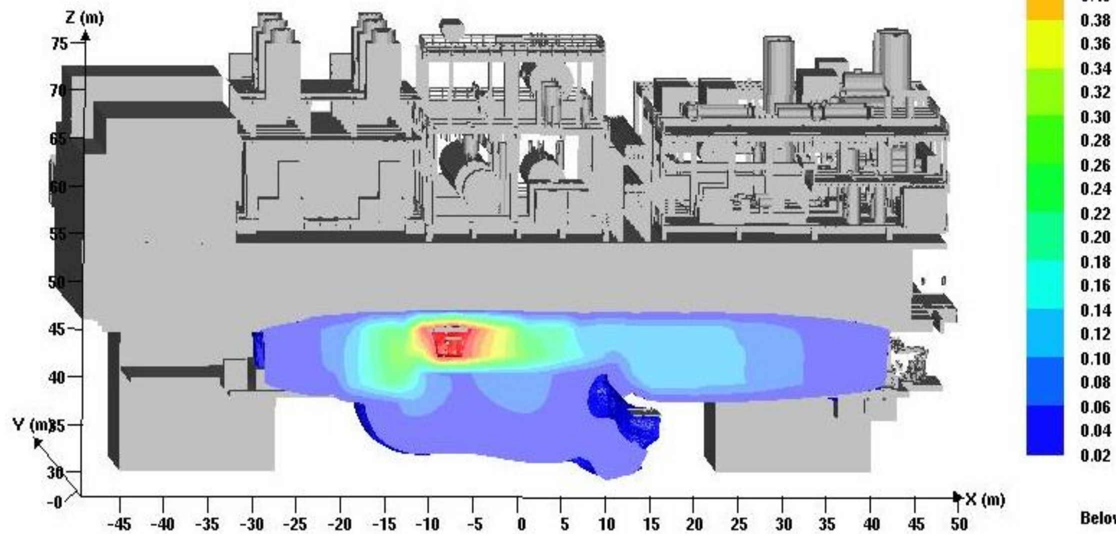


Top view

Explosion pressure wave, *t* = 1.24 s

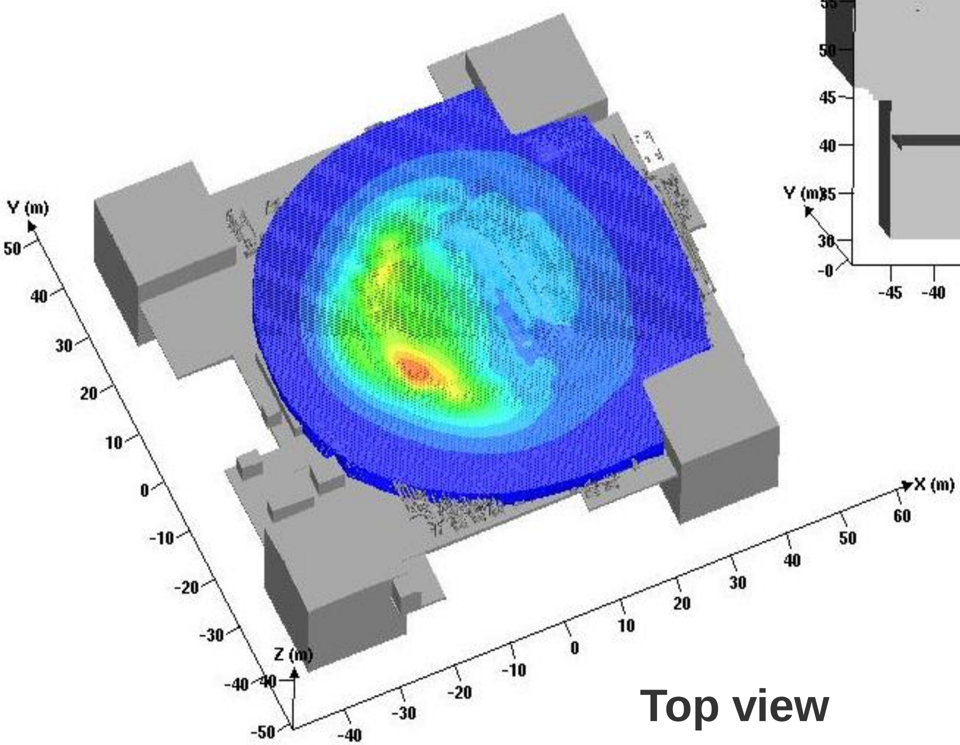
2

Above 0.5 barg



0 barg

Side view

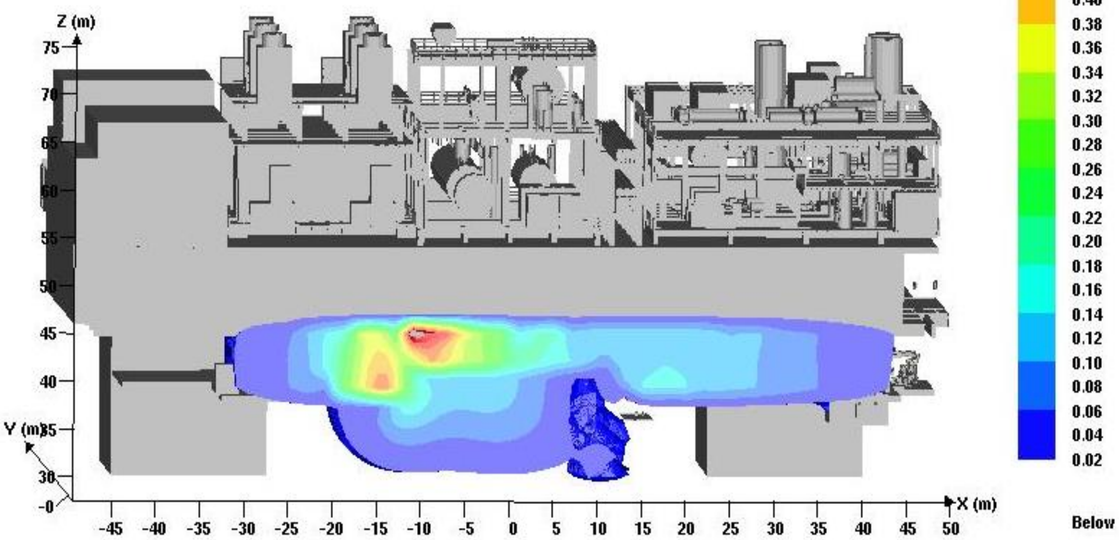


Top view

Explosion pressure wave, *t* = 1.25 s

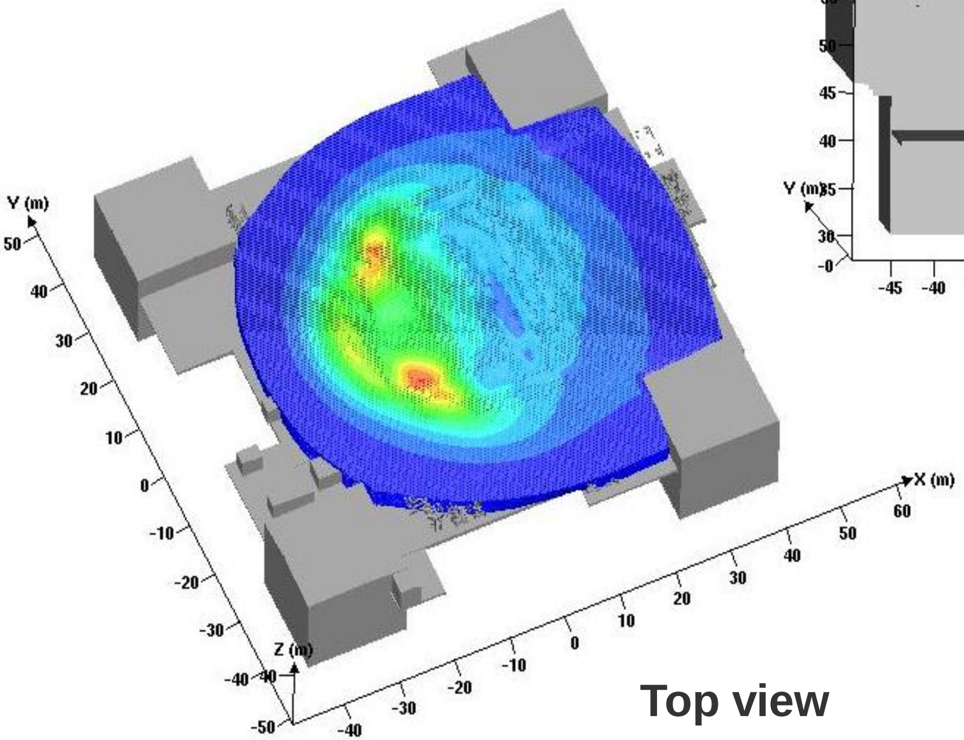
2

Above 0.5 barg



0 barg

Side view

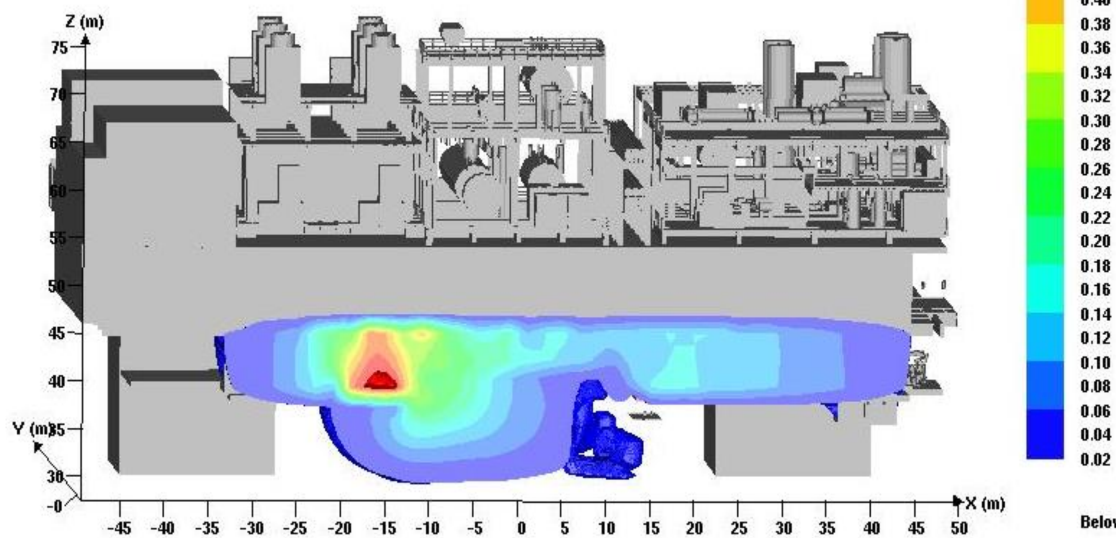


Top view

Explosion pressure wave, *t* = 1.253 s

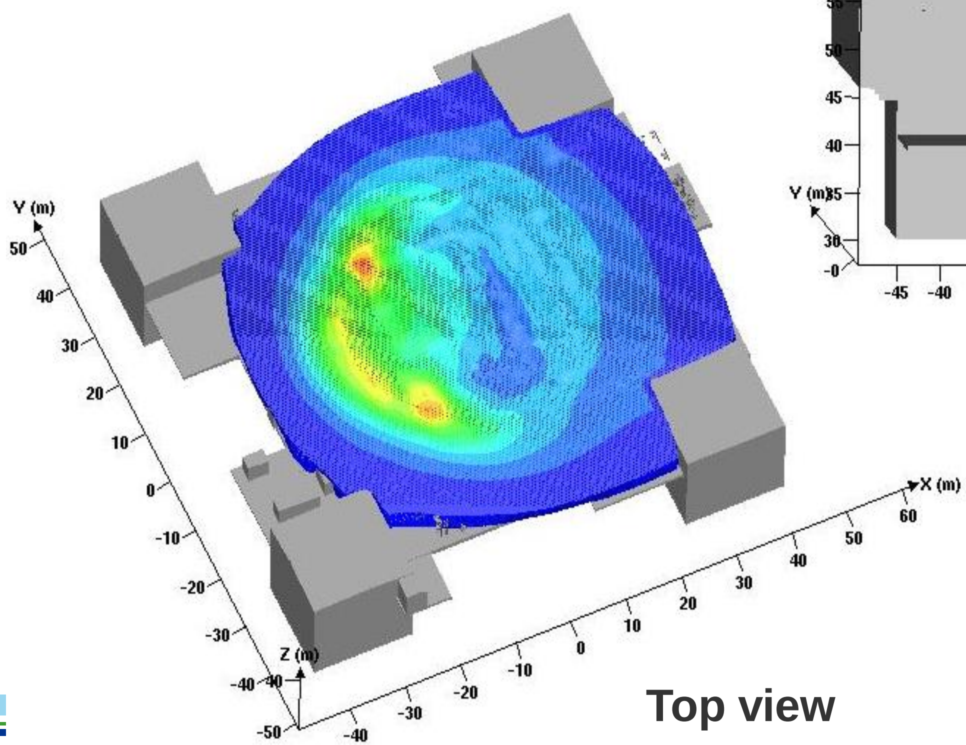
2

Above 0.5 barg



0 barg

Side view

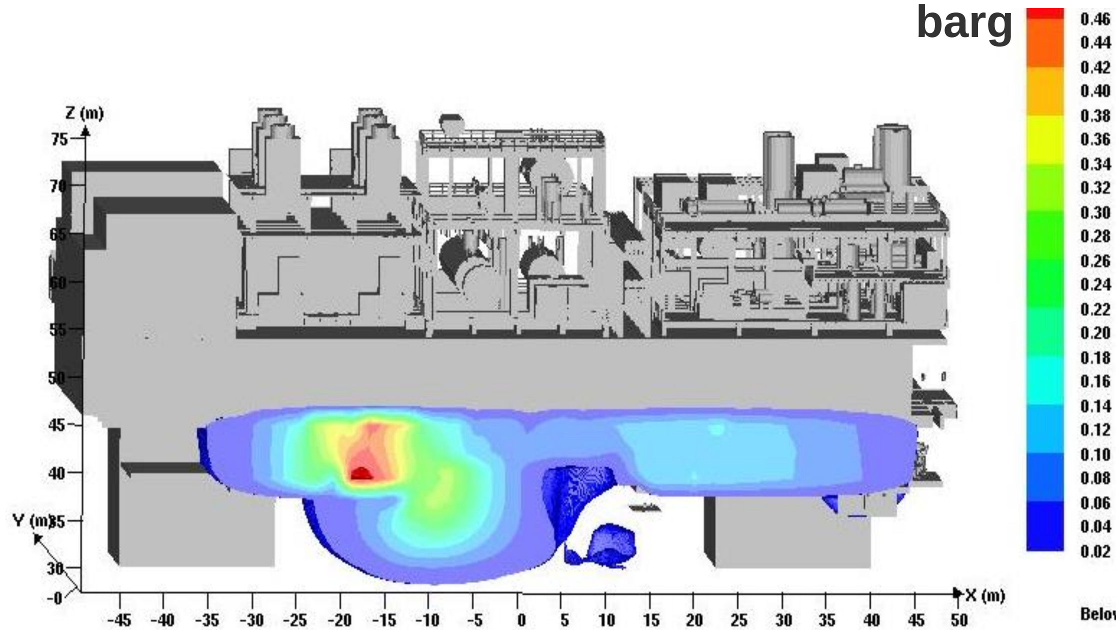


Top view

Explosion pressure wave, *t* = 1.26 s

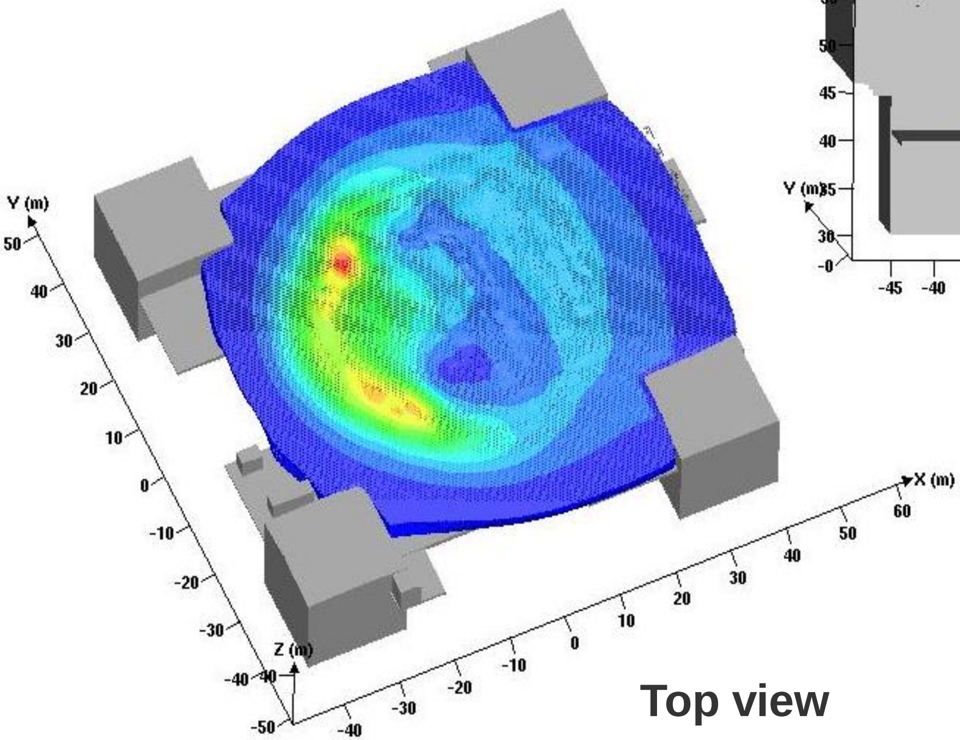
2

Above 0.5 barg



0 barg

Side view

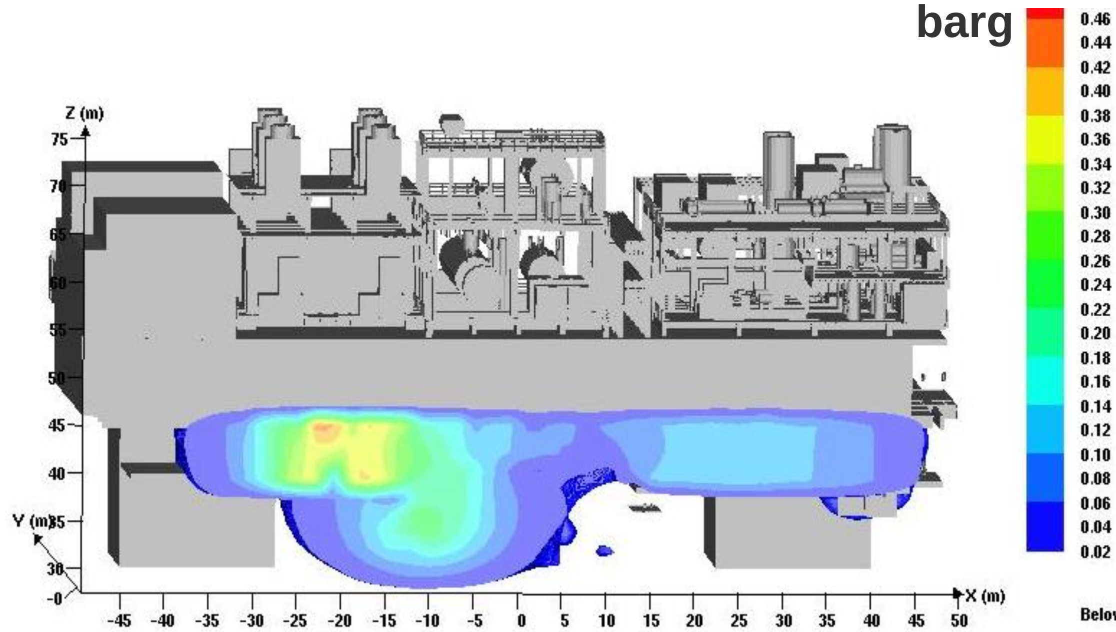


Top view

Explosion pressure wave, *t* = 1.27 s

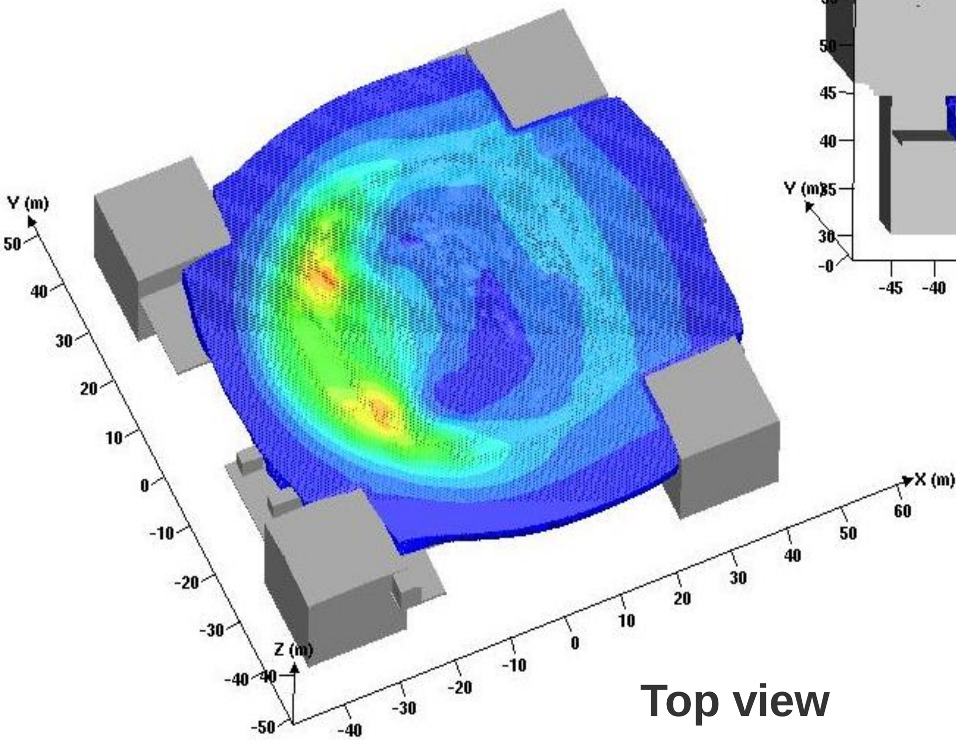
2

Above 0.5 barg



0 barg

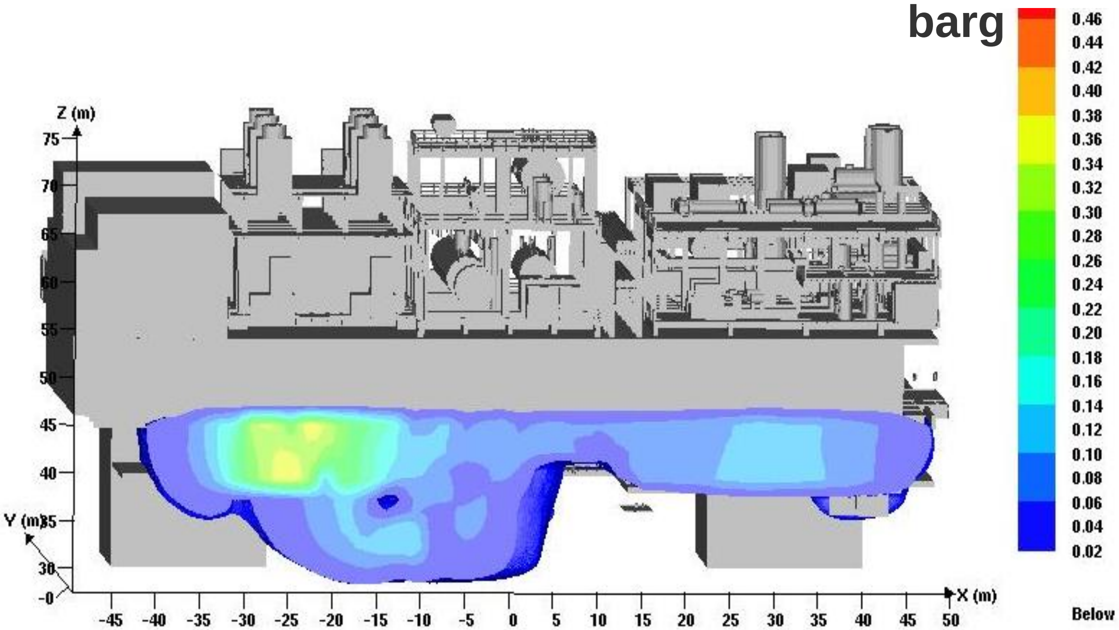
Side view



Top view

Explosion pressure wave, *t* = 1.28 s

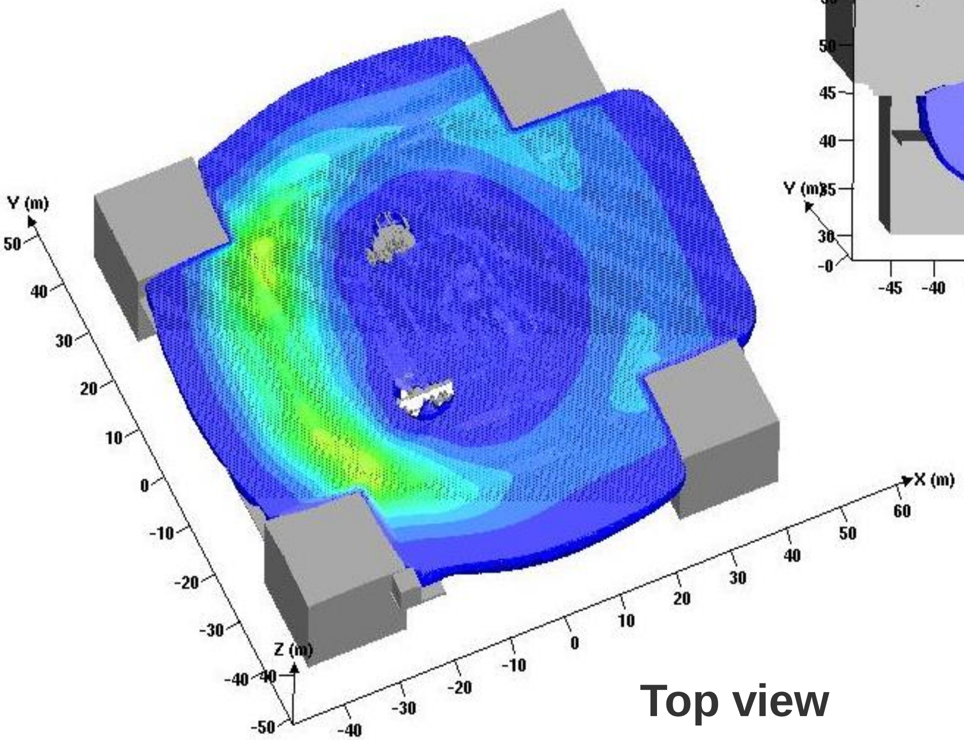
2



Above 0.5 barg

0 barg

Side view

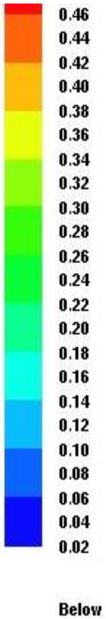


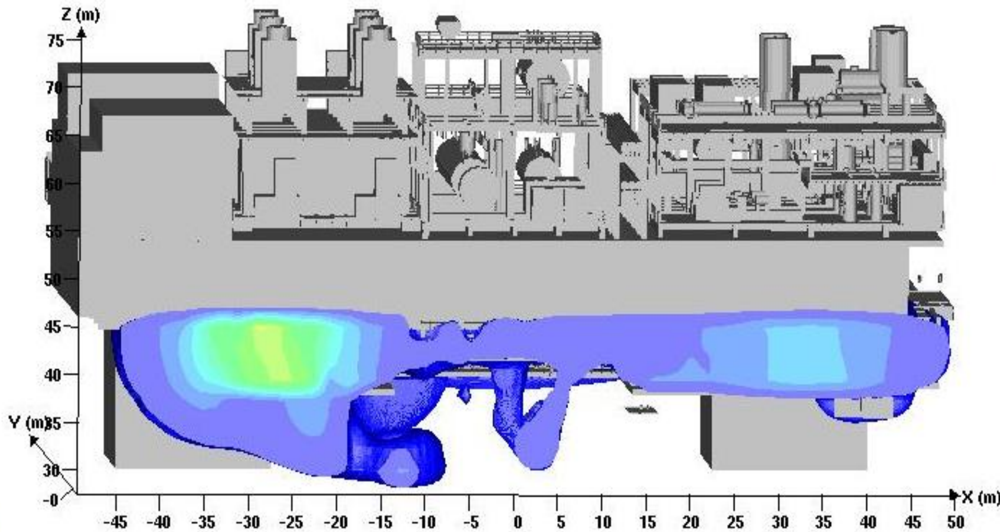
Top view

Explosion pressure wave, *t* = 1.29 s

2

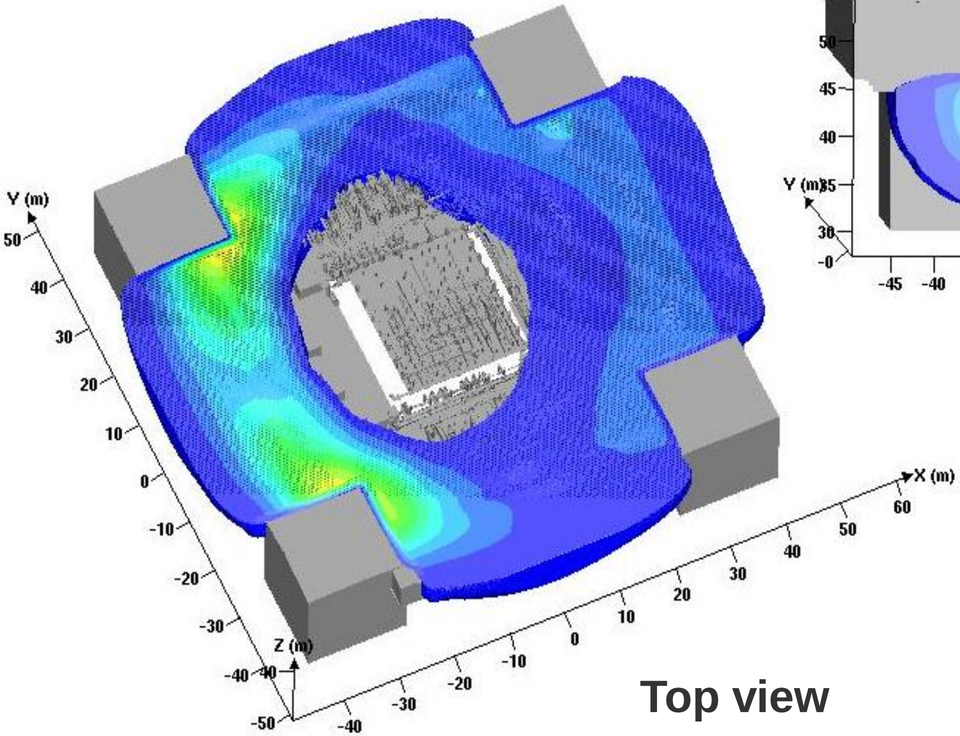
Above 0.5 barg





Side view

0 barg

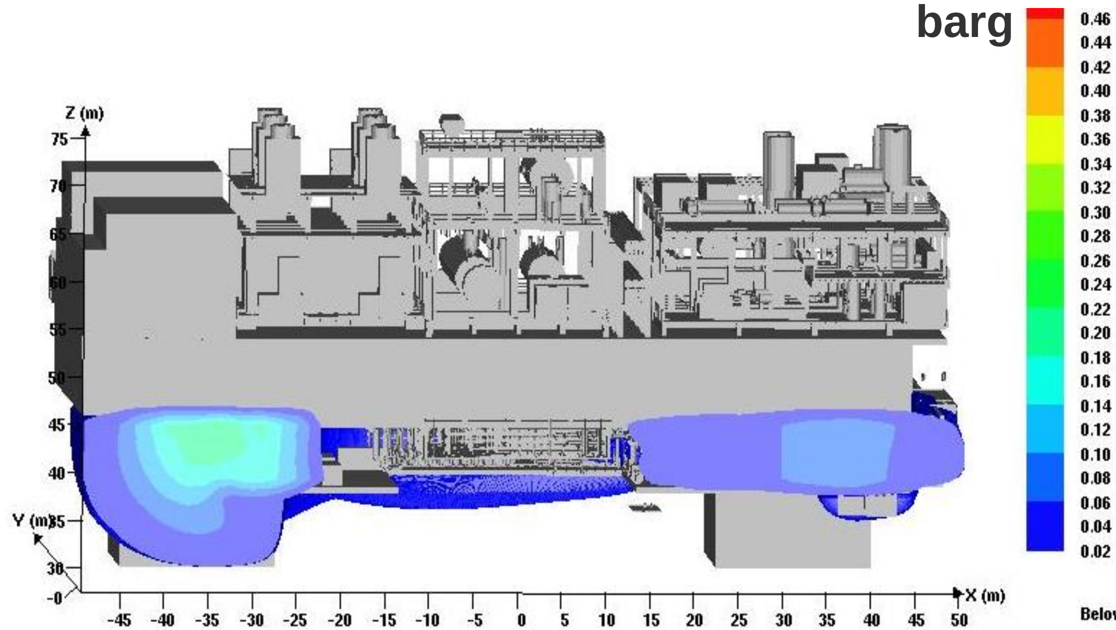


Top view

Explosion pressure wave, *t* = 1.295 s

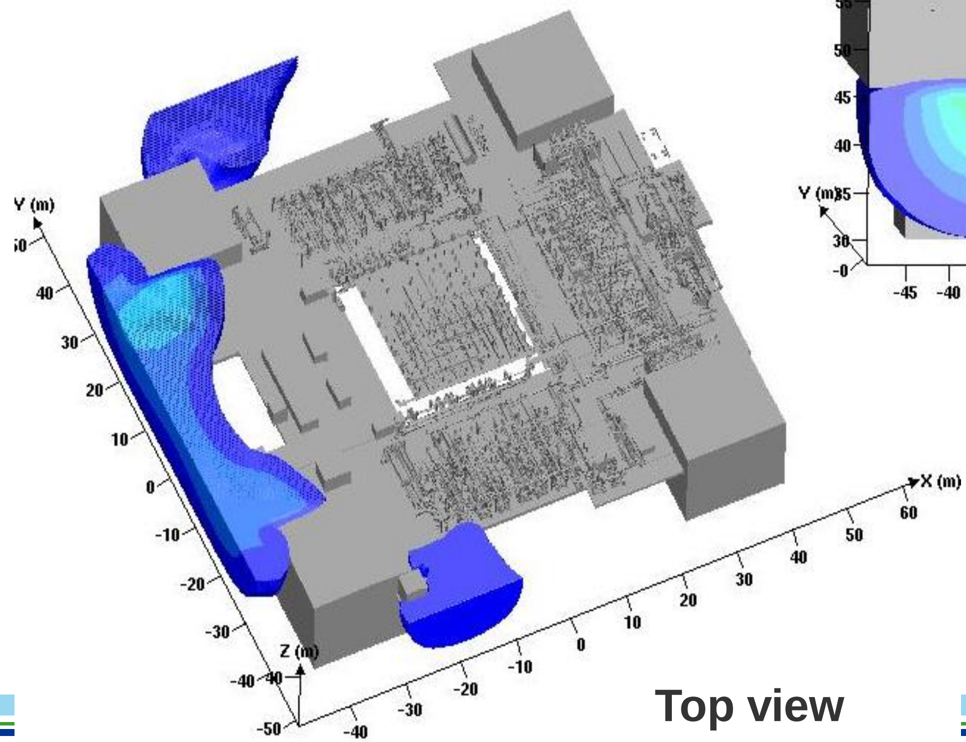
2

Above 0.5 barg



0 barg

Side view

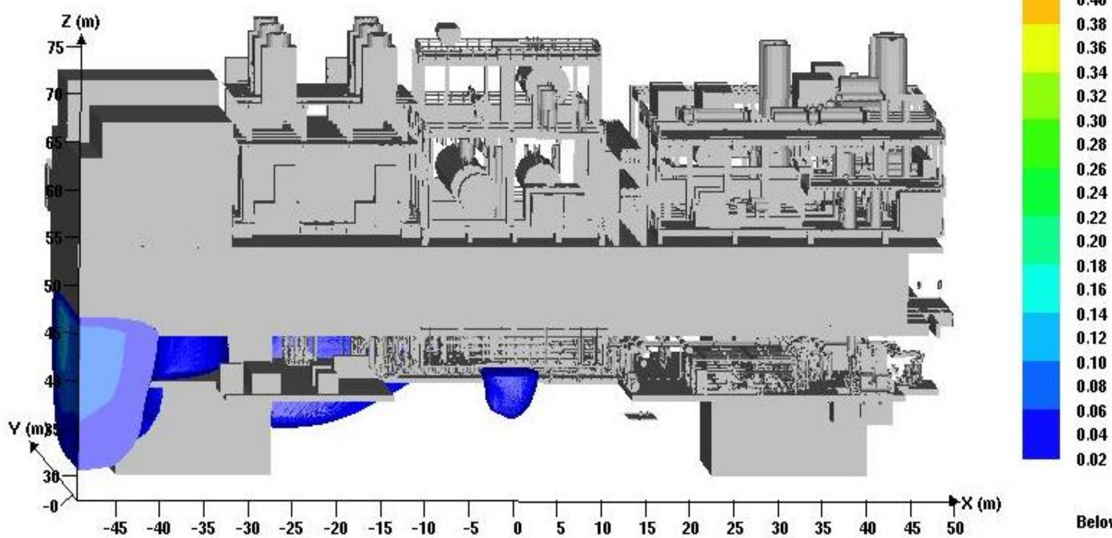


Top view

Explosion pressure wave, *t* = 1.3 s

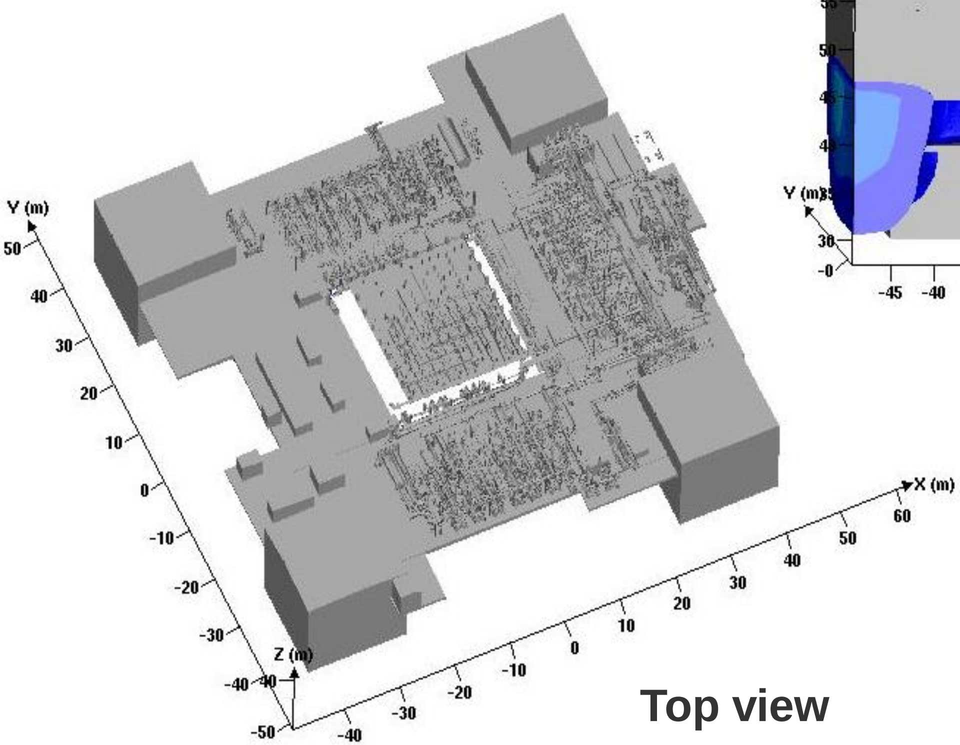
2

Above 0.5 barg



0 barg

Side view

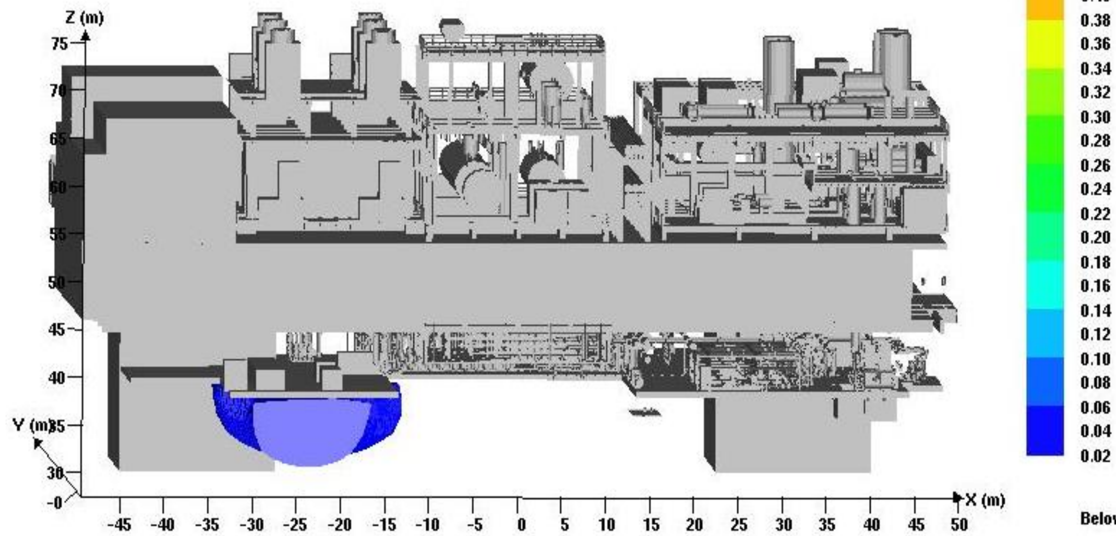


Top view

Explosion pressure wave, *t* = 1.32 s

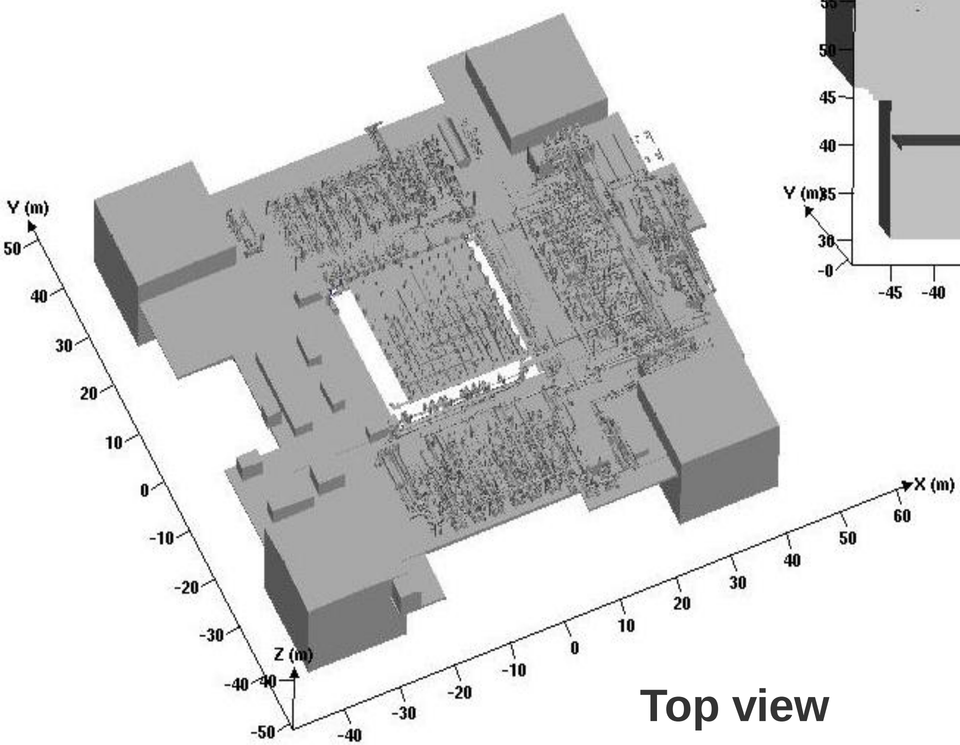
2

Above 0.5 barg



0 barg

Side view



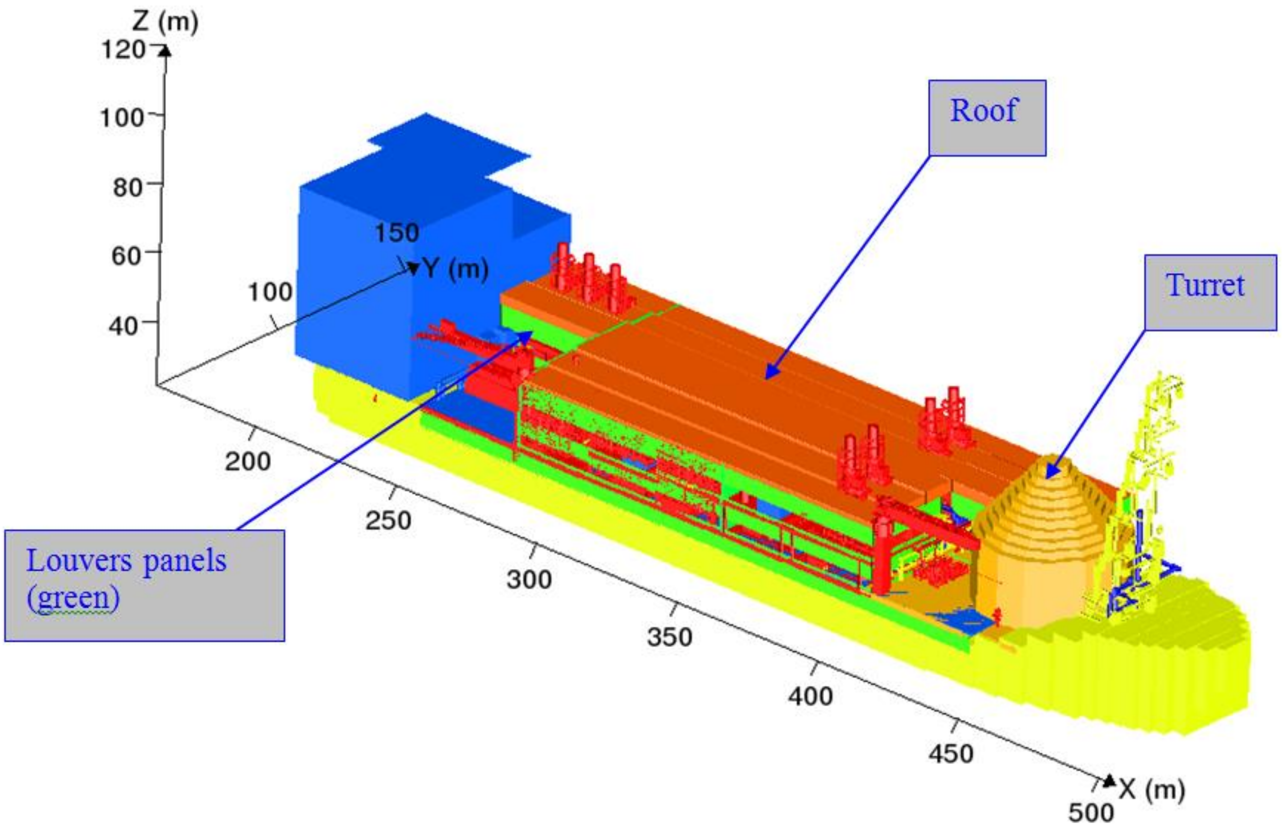
Top view

Physics highlights

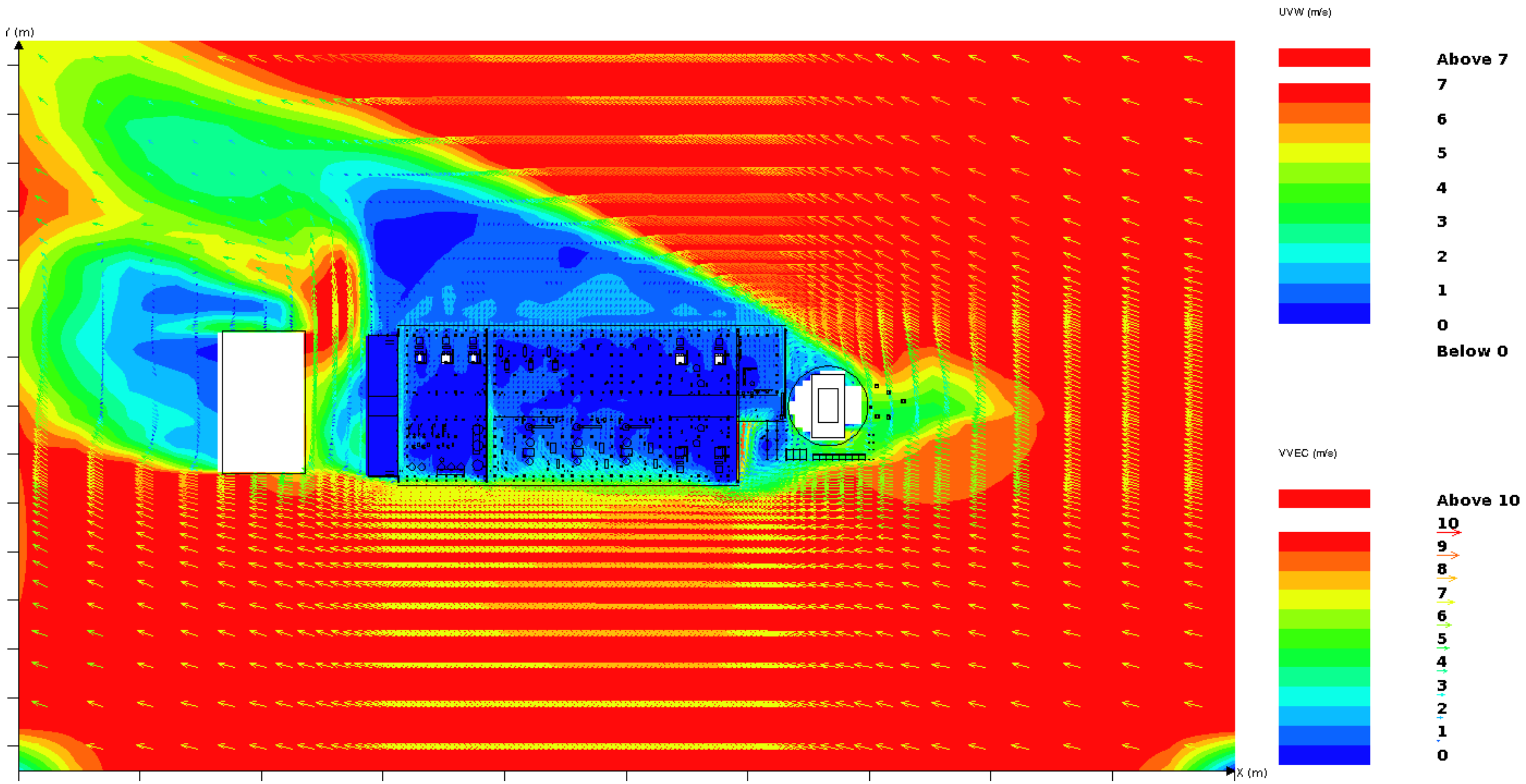
- Ventilation should be good before leak starts to dilute the gas
- Gas cloud develops fast, within 30-60 s for large leaks.
  - Light gas collects under roofs
  - Heavy gas spreads along deck
- Explosion starts slow and then … boom!
  - Effects that decides when it takes off and how high it gets:
    - Size (distance) of combustible gas cloud
    - Congestion
    - Confinement

Example FPSO in arctic

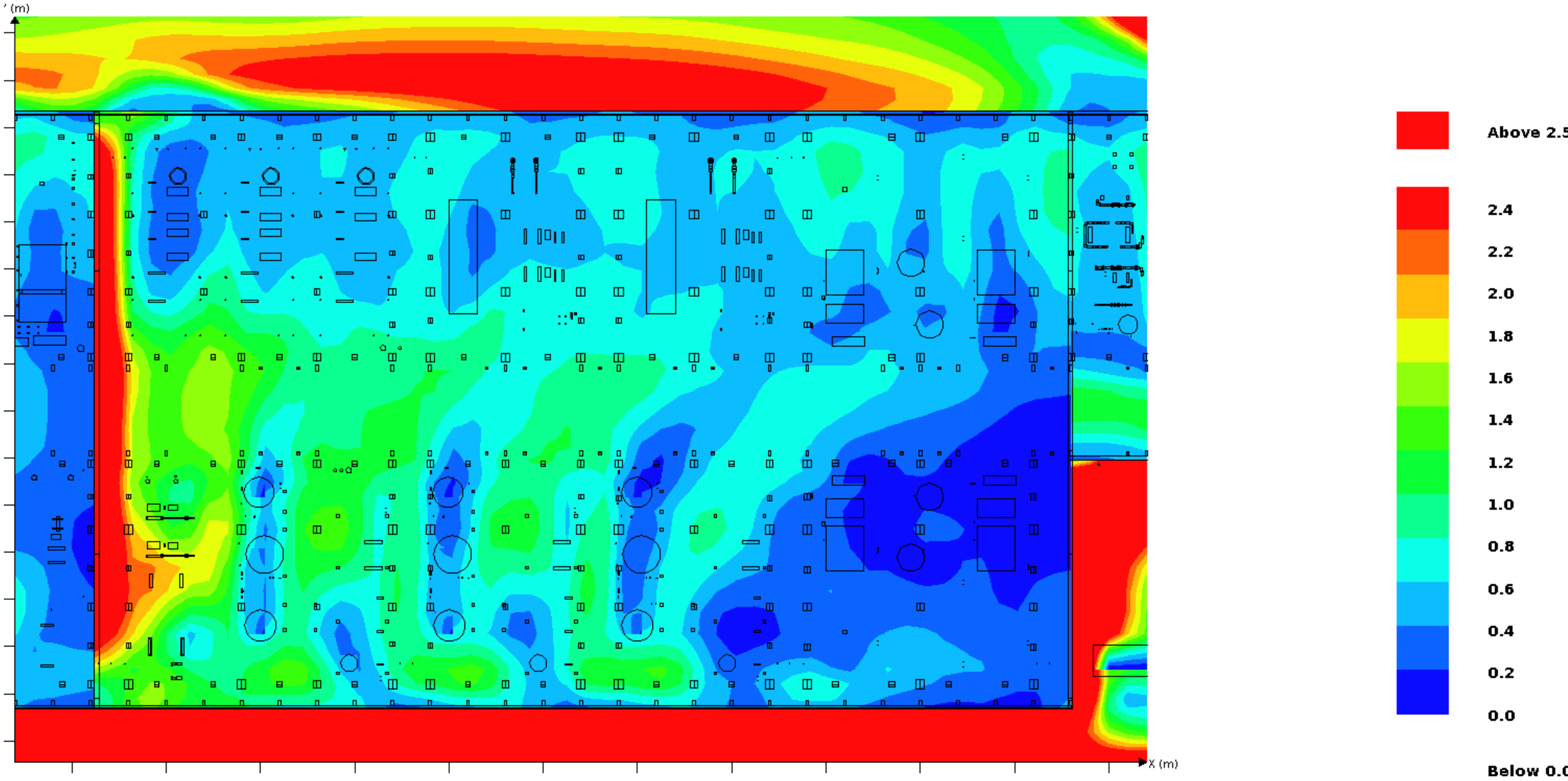
- Turret moored FPSO
- Winterized process area



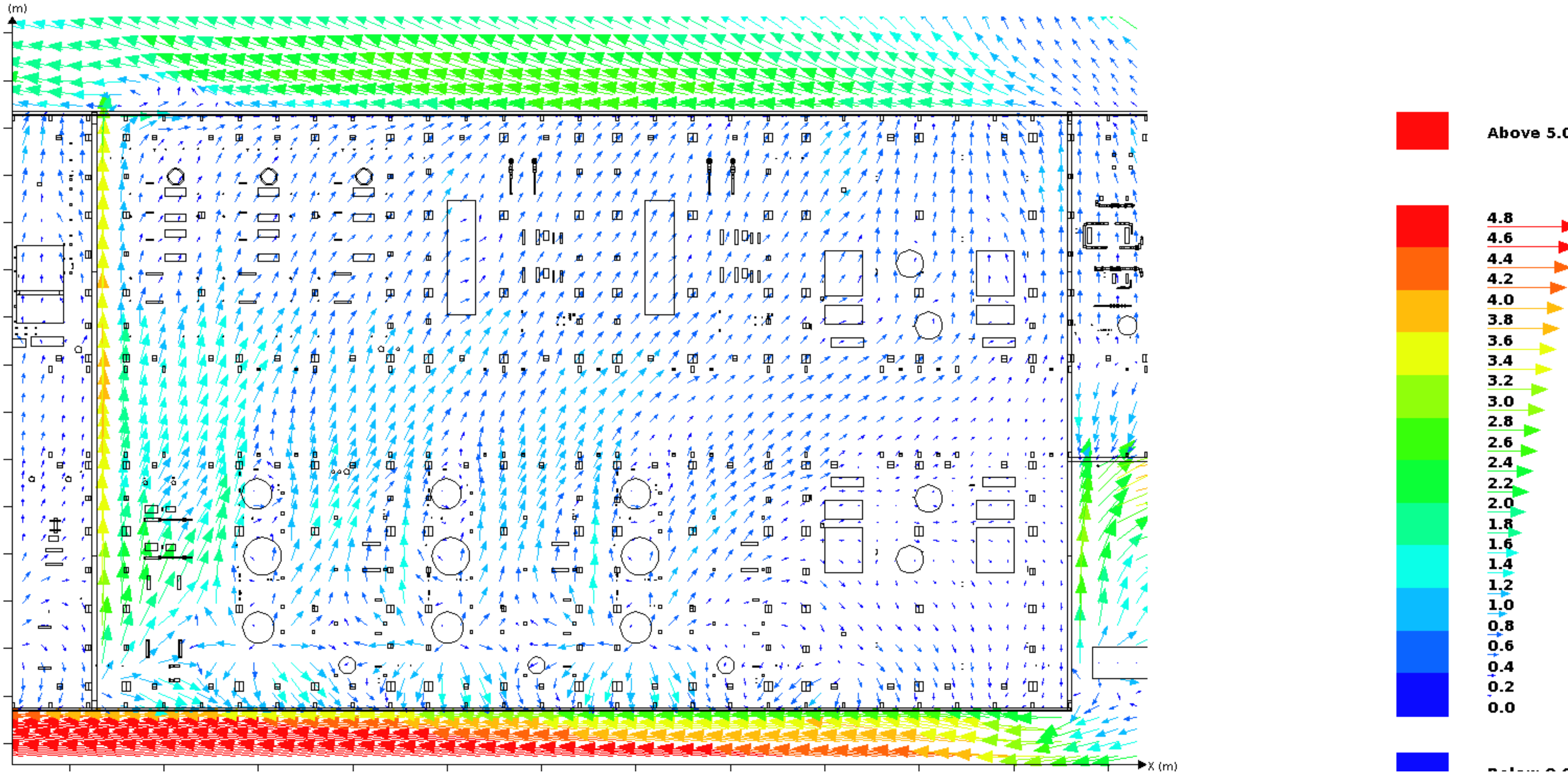
15 deg wind heading



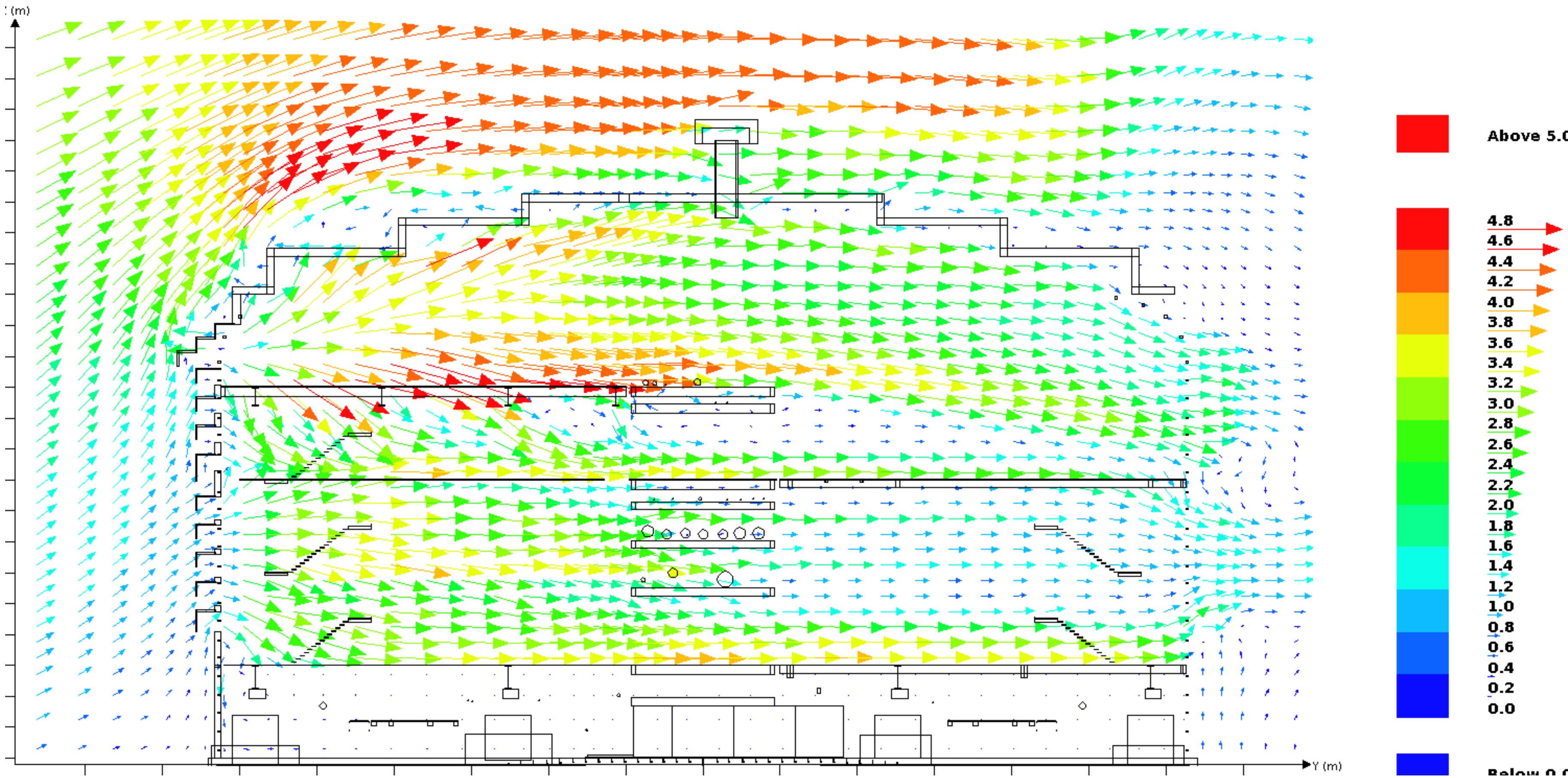
Wind sped inside process area, 15 deg heading



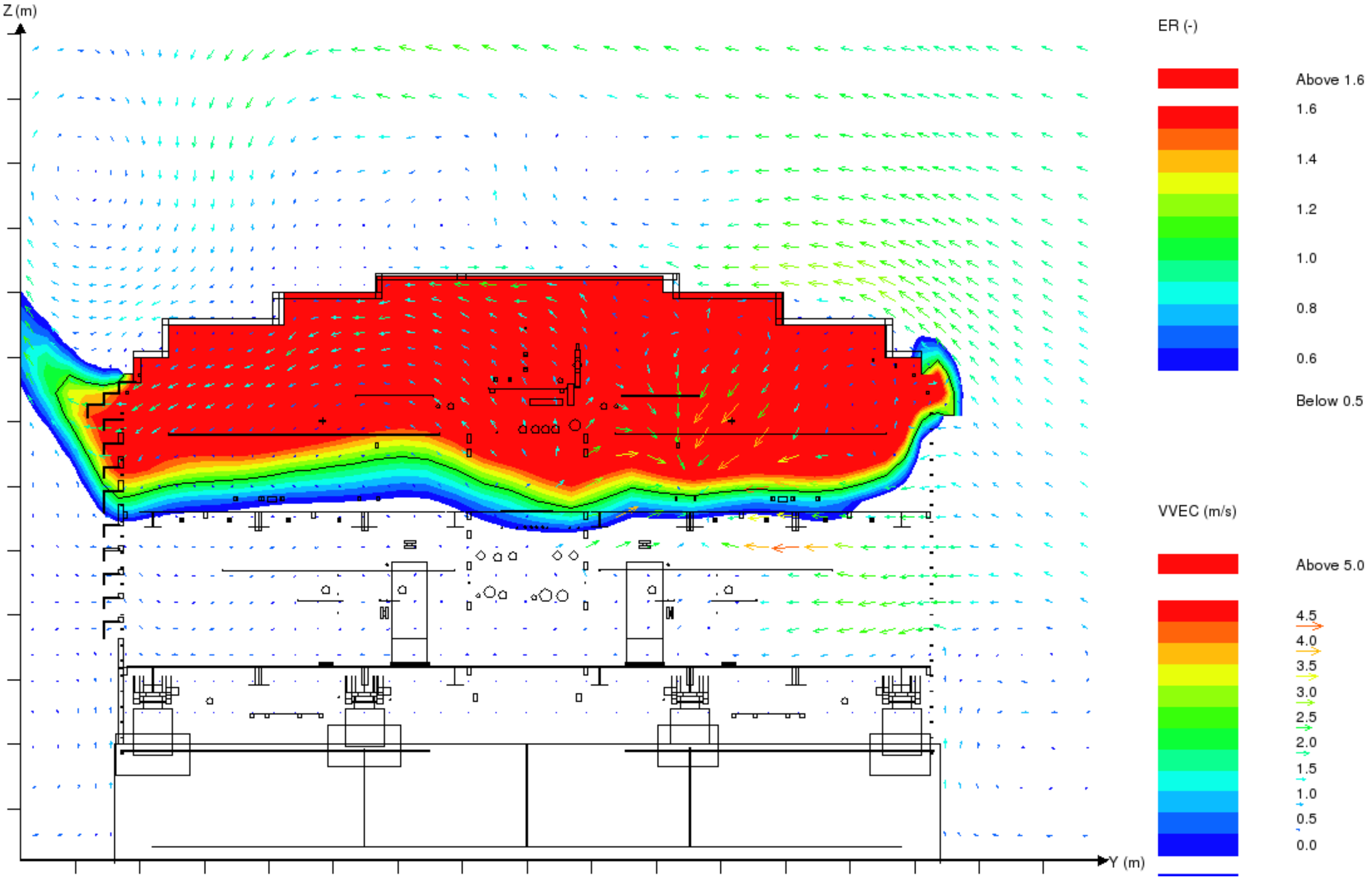
Velocity vectors, 15 deg heading



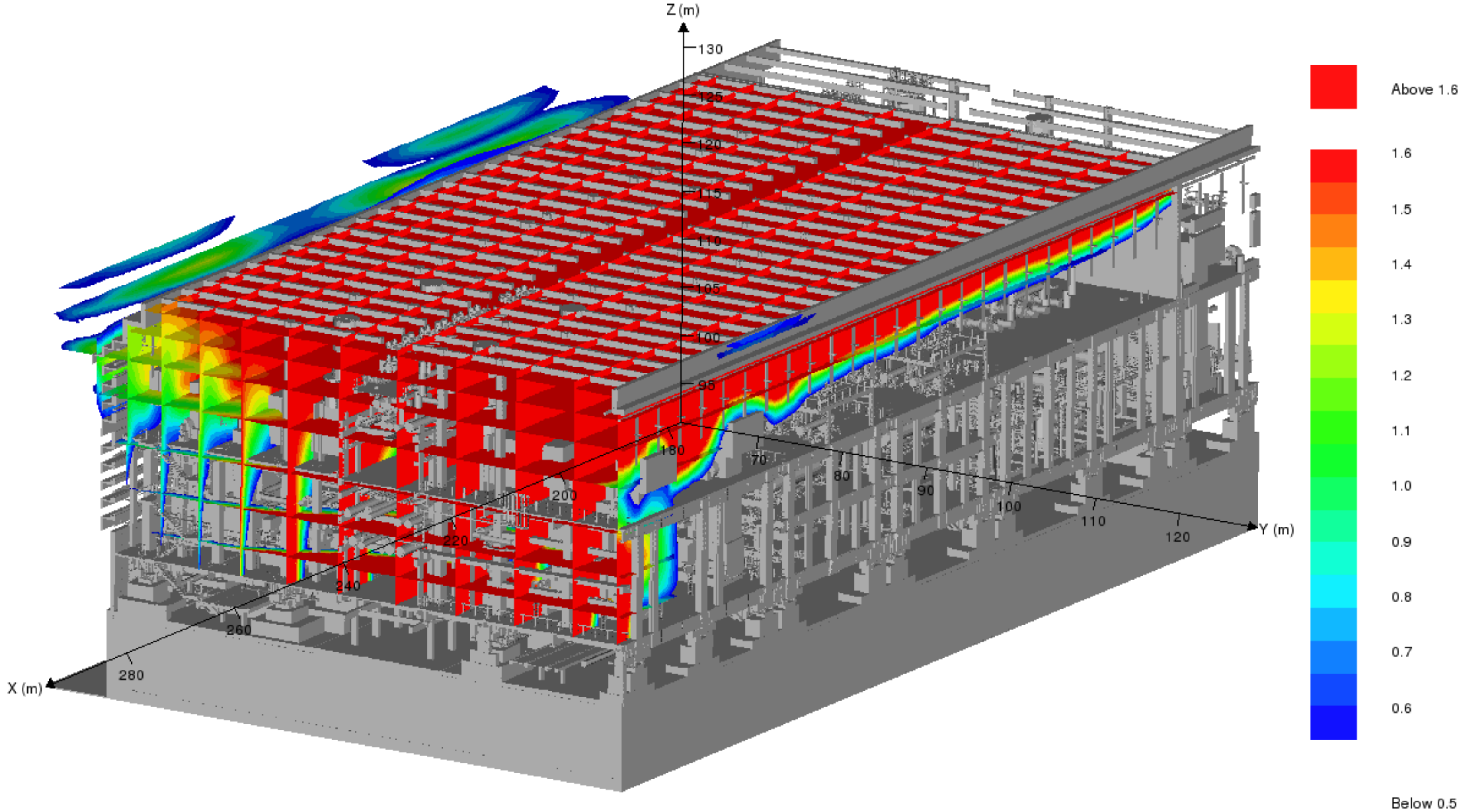
Velocity vectors transverse planne, 15 deg heading



Example dispersion simulations. Gas under roof – light gas



Example dispersion simulations. Gas under roof

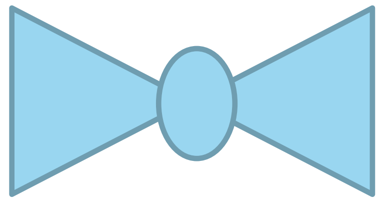


Job=012114. Var=ER (-). Time= 300.003 (s).
X=180 : 294.5, Y=62 : 129, Z=93 : 132 m

Applied designs that prevents and mitigates explosions

ignition

Prevent:
Ventilation
Dispersion



Mitigate:
Venting
Explosion
Fire

- Preventive effects are preferred over mitigating effects
  - Reduces both explosion and fire risk
- Focus on improving ventilation and dispersion
  - Inherent safe design
  - Active ventilation control
    - Active weather panels
    - Platform orientation

Wind Chill and Outdoor Operations

Theory and principles

Theory and Principles - Cold Challenges

- Cold stress factors
  - Wind
  - Precipitation and moisture
  - Low temperatures
  - Direct exposure to cold surfaces
  - Activity
  - Work clothing
- Wind chill and outdoor operations
  - Wind chill temperature (°C)

$$t_{WC} = 13{,}12 + 0{,}6215 \cdot t_a - 11{,}37 \cdot v_{10}^{0{,}16} + 0{,}396\,5 \cdot t_a v_{10}^{0{,}16}$$

  - Effective Heat Loss per time, WCI (W/m2) (ISO/TR 11079)

$$I_{WC} = 1.16\left(10.45 + 10u^{\frac{1}{2}} - u\right)(33 - T)$$

Effective temperatures considering wind chill

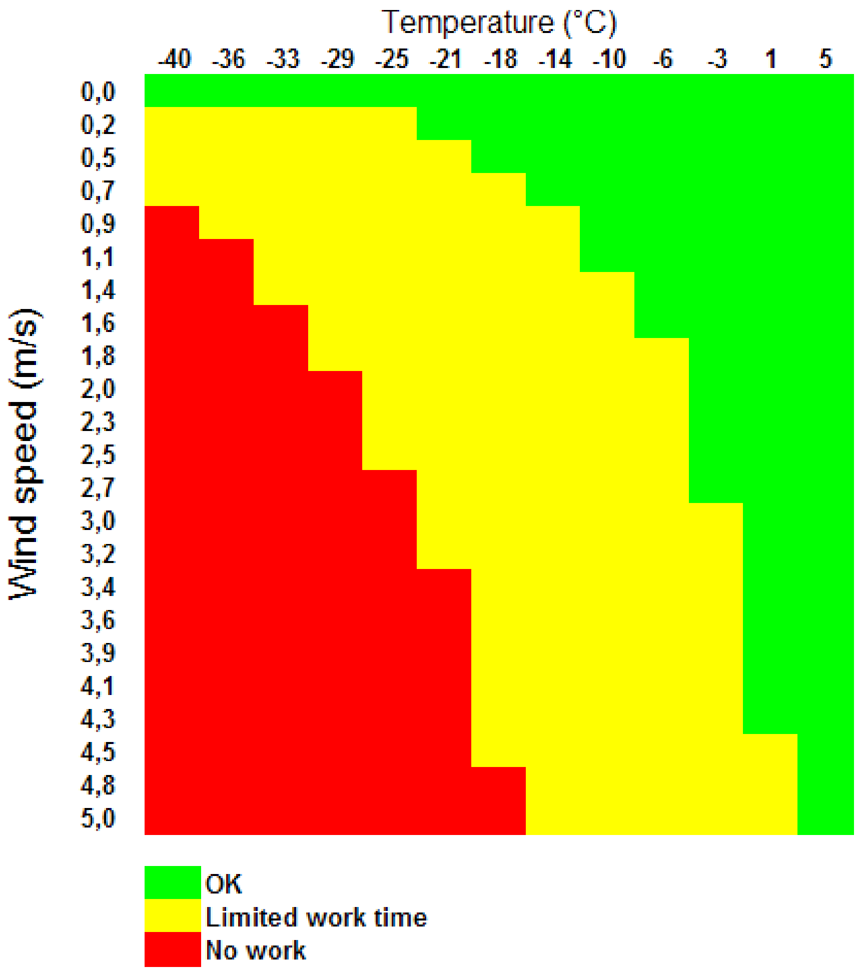
Effective temperature as function of wind and ambient temperature
(ISO11079:2007 / ISO 15743; Ergonomics of the thermal environmet. Cold workplaces Risk assessment and management)

Vind (km/t)	T_{luft} (°C)	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
Flau vind	5	4	-2	-7	-13	-19	-24	-30	-36	-41	-47	-53	-58
Svak vind	10	3	-3	-9	-15	-21	-27	-33	-39	-45	-51	-57	-63
Lett bris	15	2	-4	-11	-17	-23	-29	-35	-41	-48	-54	-60	-66
Laber bris	20	1	-5	-12	-18	-24	-30	-37	-43	-49	-56	-62	-68
	25	1	-6	-12	-19	-25	-32	-38	-44	-51	-57	-64	-70
Frisk bris	30	0	-6	-13	-20	-26	-33	-39	-46	-52	-59	-65	-72
	35	0	-7	-14	-20	-27	-33	-40	-47	-53	-60	-66	-73
Liten kuling	40	-1	-7	-14	-21	-27	-34	-41	-48	-54	-61	-68	-74
	45	-1	-8	-15	-21	-28	-35	-42	-48	-55	-62	-69	-75
Stiv kuling	50	-1	-8	-15	-22	-29	-35	-42	-49	-56	-63	-69	-76
	55	-2	-8	-15	-22	-29	-36	-43	-50	-57	-63	70	-77
	60	-2	-9	-16	-23	-30	-36	-43	-50	-57	-64	-71	-78
Sterk kuling	65	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79
	70	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-80
Liten storm	75	-3	-10	-17	-24	-31	-38	-45	-52	-59	-66	-73	-80
	80	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81

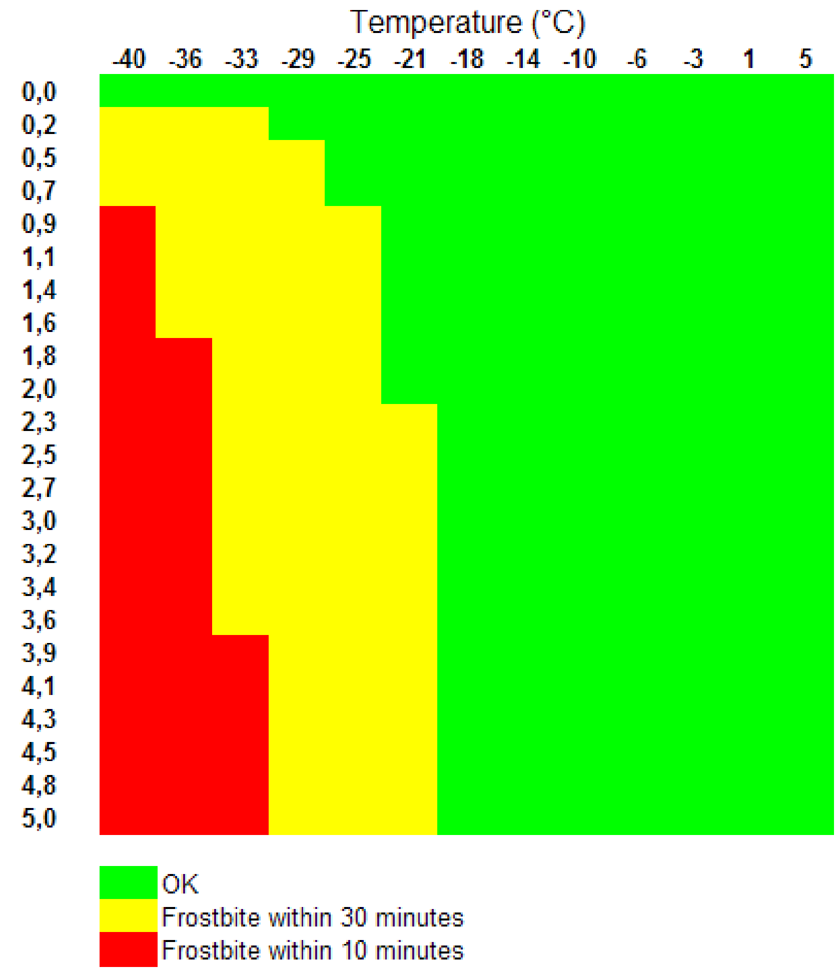
Uncomfortably cold
Very cold, risk for frost bites
Risk for skin frost damage after 10 min
Risk for skin frost damage after 2 min

NORSOK and US limitations

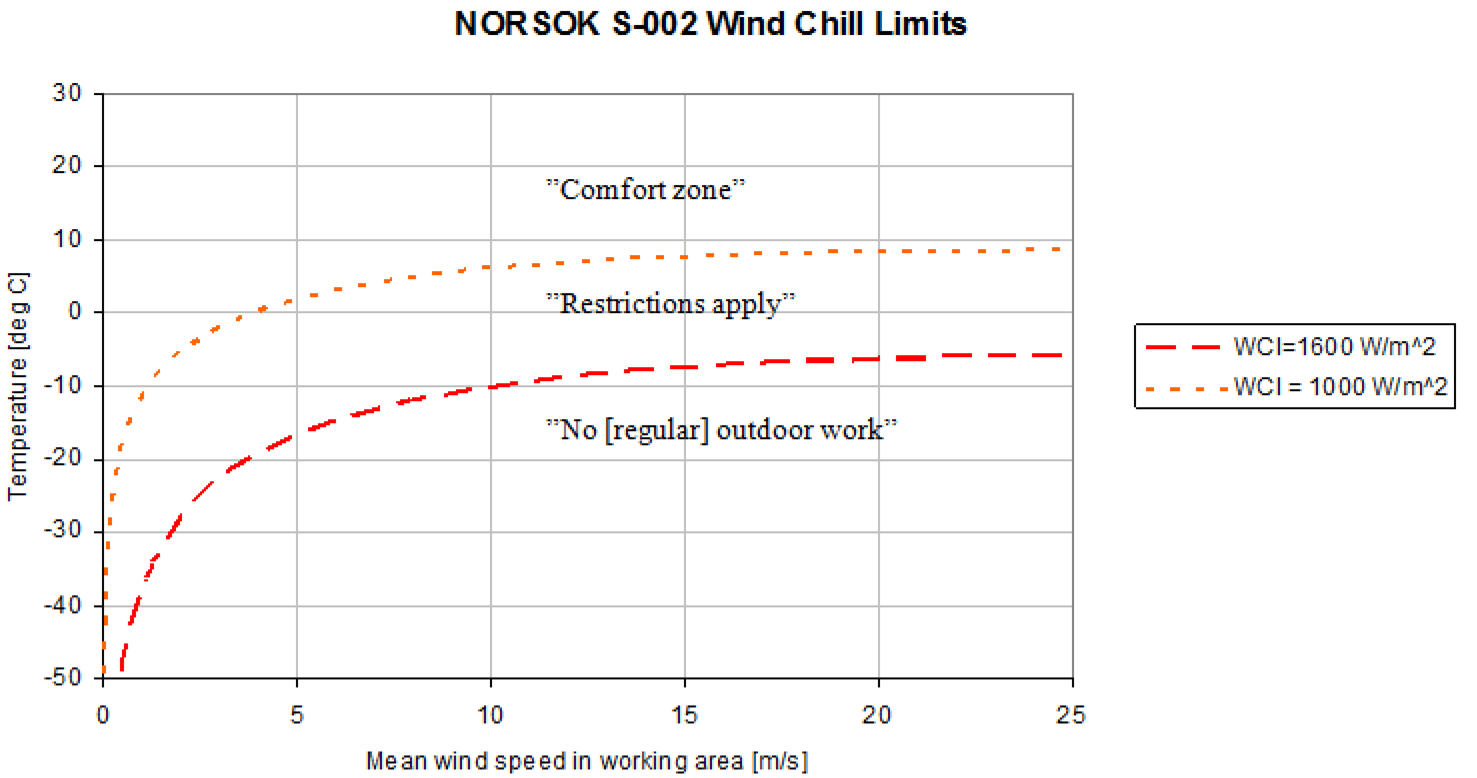
NORSOK



US NWS



Effective Heat Loss per time (ISO/TR 11079 - NORSOK S-002, 2004 reference)



$$I_{WC} = 1.16\left(10.45 + 10u^{\frac{1}{2}} - u\right)(33 - T)$$

Other influences

- Night work – increased heat loss
- Age – Lowered tolerance
- Sex – Men tolerate cold better
- Ethnical differences – Polars benefit
- Medical conditions – heart, Reynaud (likfingre)
- Work intervals

Opimize design:

- Wind walls and enclosures to provide weather protection

Potenital explosion risks due to confinement and enclosures:

- Gas cloud build-up
- No explosion relief

Balancing Process safety vs Working environment

Requirements:

- NORSOK S-002, Section 4.4.9/5.8

- NORSOK S-001, Section 15.4.1

Practice

- NORSOK Z013 annex F

TYPICAL SCOPE ERA and Wind Chill Analysis

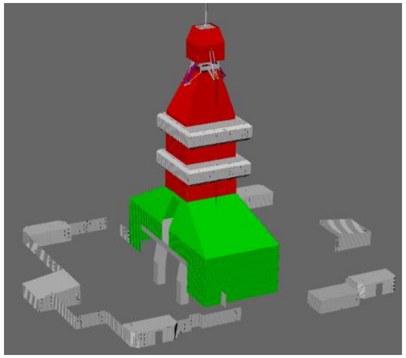
ERA and ACH Assessment

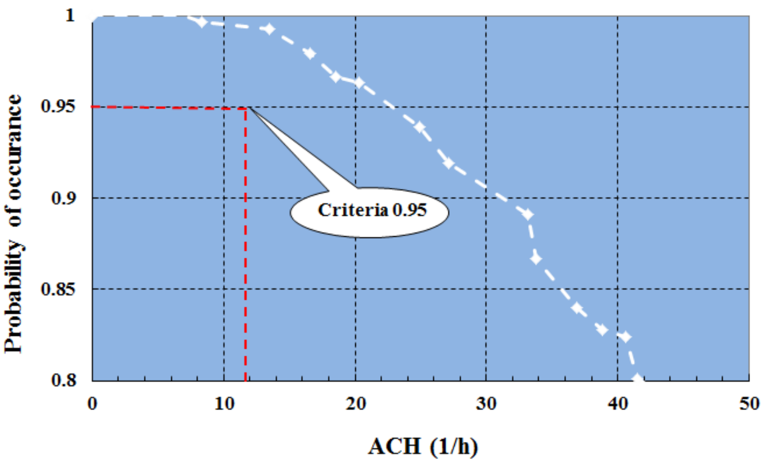
Obtain DAL pressures from ERA. Assess if DAL is acceptable

- NORSOK Z013 Annex F is followed
- Use same geometry model for WCI sims

Assess if minimum required ventilation rate is obtained

- Assess NORSOK S001 criteria of minimum 12 ACH 95% of the time
  - ACH exceedance curve found by combining wind rose with ventilation simulation results
  - The upper 95% ACH percentile read off the curve

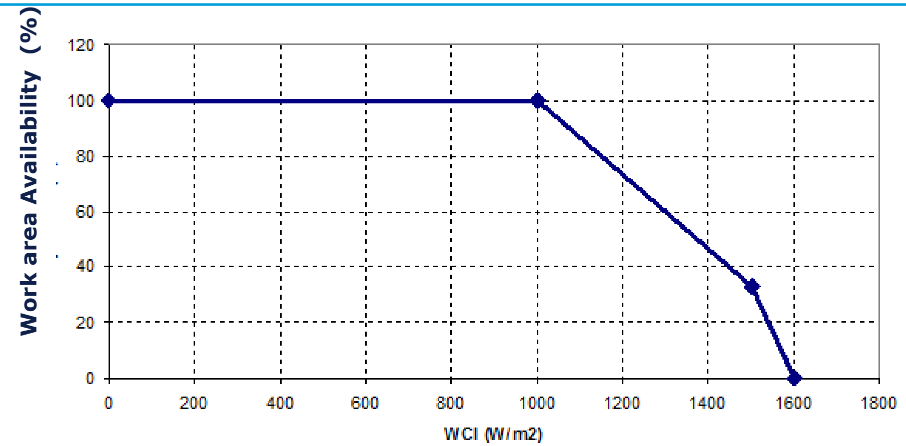


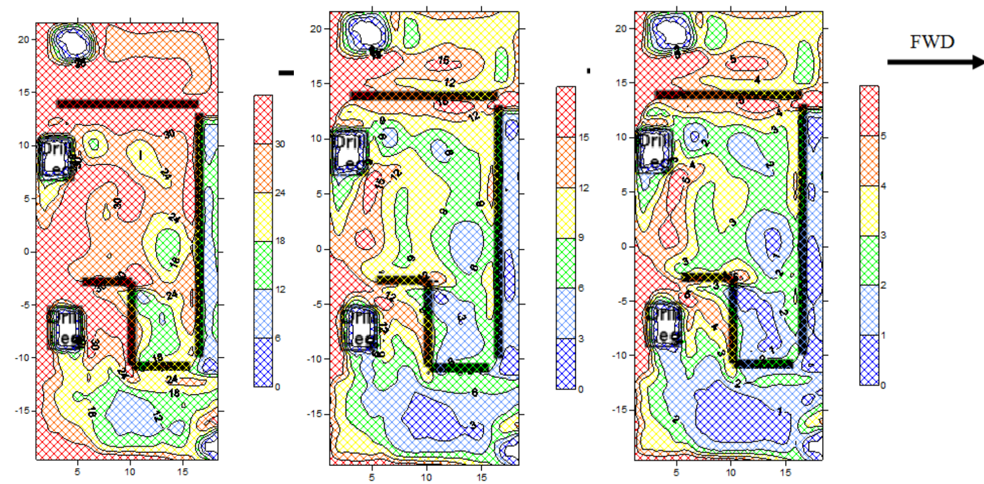


WCI distribution calculations: Unavailability

WCI distribution for work areas calculated and assessed towards criteria

- Unavailability calculations considering
  - Distribution of WCI levels
  - Availability per WCI level
  - Work area distribution
- Criteria:
  - Yearly unavailability < 2%



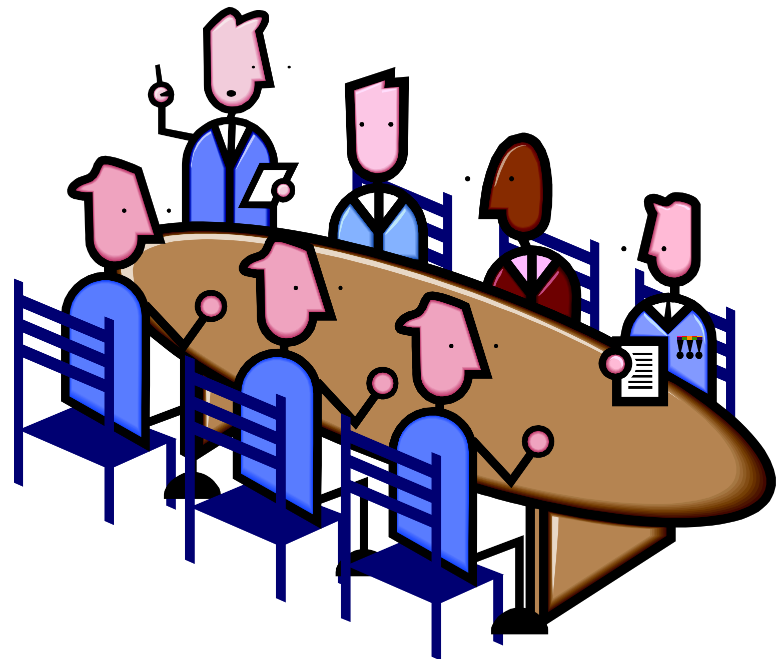


Geometry → Ventilation simulations → ERA → **WCI assessment** → Outdoor operations workshop

Outdoor Operation and safety Workshop

Identification, discussion and measures

- Different disciplines including operational personnel attending
- Use ERA and WCI assessment to point at:
  - explosion risk drivers and
  - Challenging work areas wrt wind
- Identify improvement measures
- Find solutions that works and is possible
  - Design
  - Operation
  - Further work



Geometry → Ventilation simulations → ERA → WCI assessment → **DAL and Outdoor operations workshop**

Reference Documents and Standards

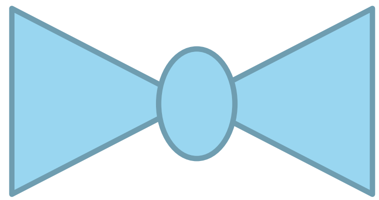
- Relevant standards
  - NORSOK S-002 Working Environment, Rev. 4, August 2004
  - NORSOK S-001 Technical Safety, Rev. 4, February 2008
  - NORSOK Z013 Annex F Procedure for Probabilistic Explosion Simulations 2010
  - ISO 15743:2008. Ergonomics of the thermal environment - Cold workplaces - Risk assessment and management, Edition 1, November 2008
  - ISO 11079:2007. Ergonomics of the thermal environment - Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects, Edition 1, December 2007
  - ISO 19906:2010. Petroleum and natural gas industries - Arctic offshore structures, Edition 1, December 2010
- Reference Reports
  - Health Aspects of Work in Extreme climates, A guide for oil and gas industry managers and supervisors. OGP Report Number 398, 2008
  - Kalde utfordringer. PSA Report number 10-31, ISBN 978-8032-024-7, May 2010,

DESIGN OPTIMIZATION

Applied designs that reduce explosions and improve working areas

ignition

Prevent by:
Ventilation
Dispersion
Plus avoid high wind



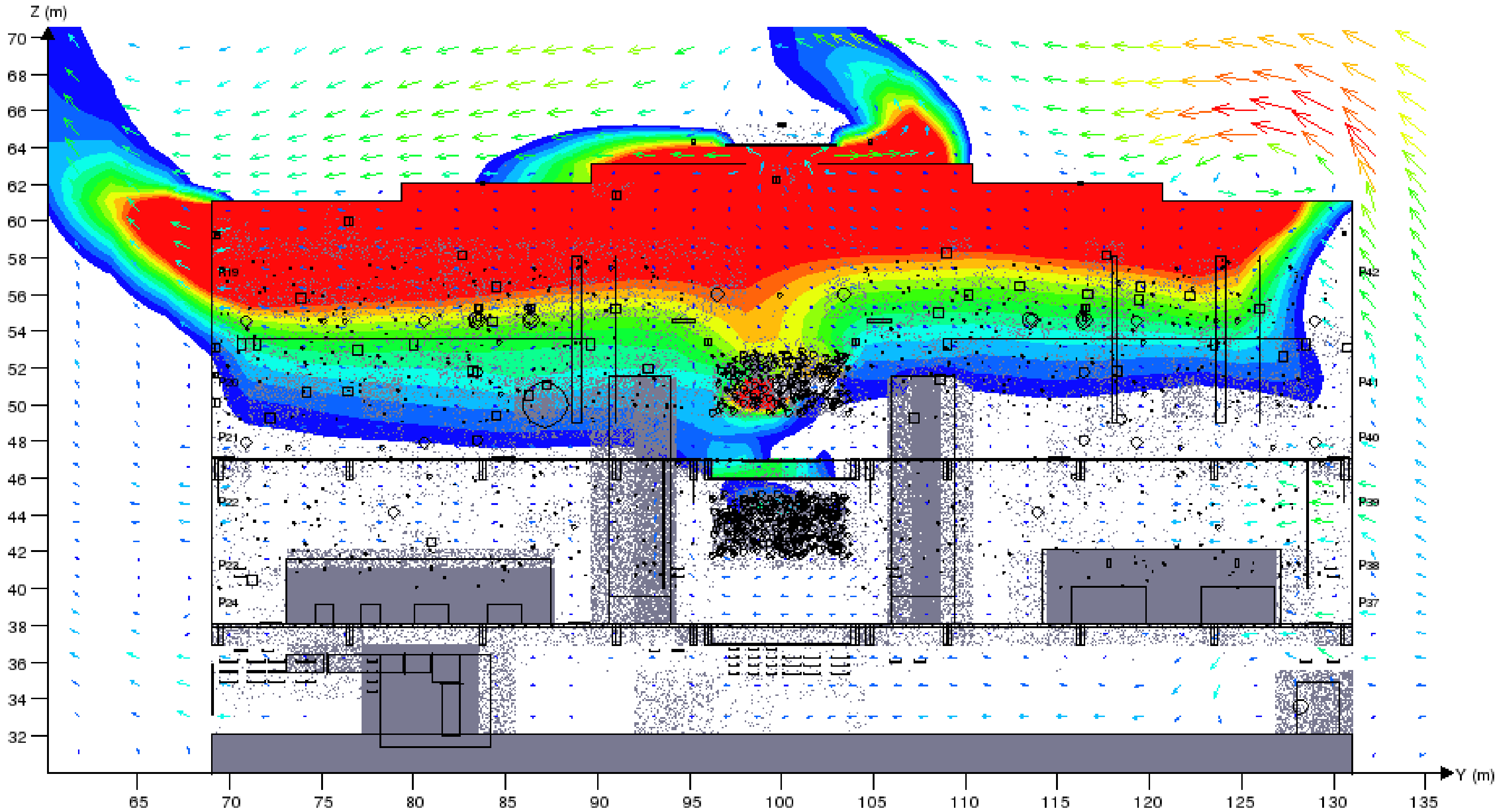
Mitigate by:
Venting
Explosion reduction
Fire reduction

- Preventive effects are preferred over mitigating effects
  - Reduces both explosion and fire risk
- Focus on improving ventilation and dispersion
  - Inherent safe and work place friendly design
  - Active ventilation control
    - Active weather panels
    - Platform orientation

Prevention by inherent safe ventilation design

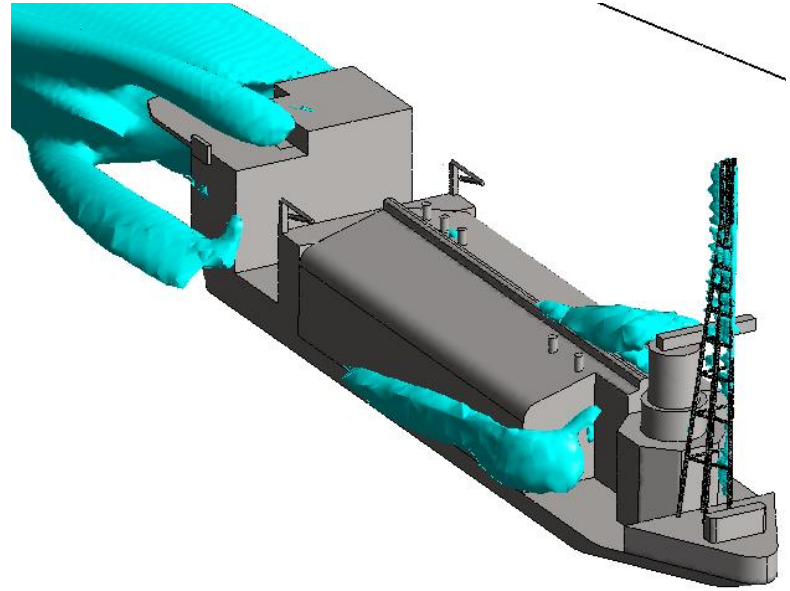
- Main air comes in through wall openings and in arctic the openings are reduced significantly
  - Optimize WCI vs. dispersion
  - Open as much as possible without breaching WCI requirements
- Avoid gas accumulation under roof
  - More openings high up on the walls
  - Roof openings

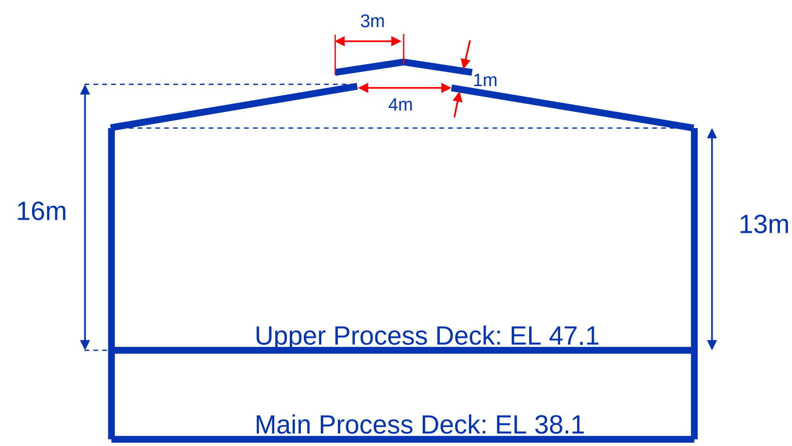
Openings along upper parts



Roof design

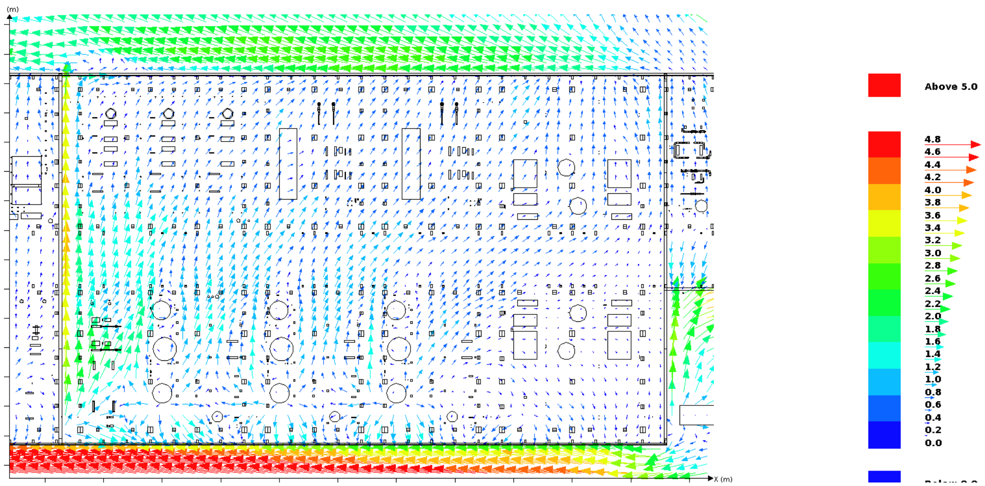
- Important to get the gas out quickly
- Permanent openings best
  - Open all along roof is best
  - Chimneys not sufficient openings
- Snow and ice challenge
  - Causes build-up of weight which stops explosion release panels
  - Snow can come into the process
  - Separate snow simulations can be performed
  - Heat tracing becomes very extensive





Prevention by inherent safe ventilation design

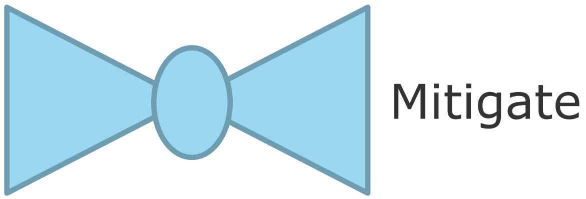
- Avoid re-circulation flow in process areas
  - FPSO Safety gaps show benefits
  - Blast walls upwind gives re-circulation and poor ventilation
- Limit size of explosion areas
  - Process areas, use plated decks between modules
  - FPSO, use plated 1st process deck
- Minimize blocking by equipment of module air inlets



Prevention by active ventilation control

- Active weather panels in walls
  - Opens when gas is detected
  - Opens when temperature is higher
  - Opens when areas are unmanned
  - New technology – ice and snow challenge
- Roof panels
  - Can open when temperature is higher
  - Snow and ice challenge
- Ventilated and heated rooms where most of work is performed
  - Challenge with leak sources inside
- FPSO active thrusters to improve ventilation
- Fans to improve ventilation: last resort
  - Requires large fans
  - Represent ignition source

Mitigation of explosions



- Congested equipment and piping away from walls and decks
- Avoid corners in walls
- Reduce congestion by more space
- Minimize blocking of module venting openings
- Use explosion panels in walls and ceilings

Preventive and/or mitigating measures

- Process:
  - Smaller segments
  - Automatic blowdown
  - Quick ESD valves
  - Shutdown of ignition sources
  - Good gas detection
- Fire protection
  - Optimize blowdown vs PFP
  - Use quick blowdown instead of PFP
  - Internal escape route
  - Avoid trapping of smoke by large items

Arctic weather protection options

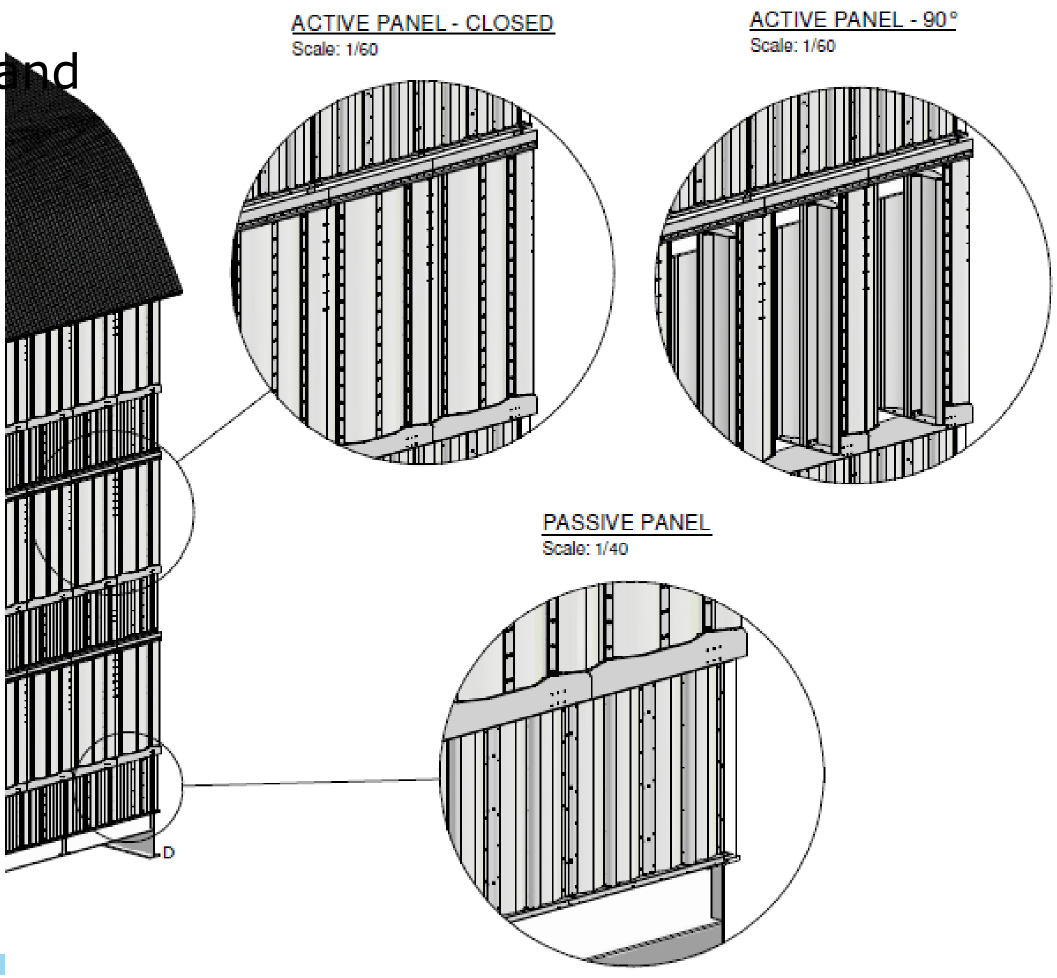
- Passive Windwalls typically used in the North Sea
  - Wind cladding
  - Porous windwalls
  - Louvres
  - Explosion release panels

- Active weather panels

- Roof design

Active Panel Geometry

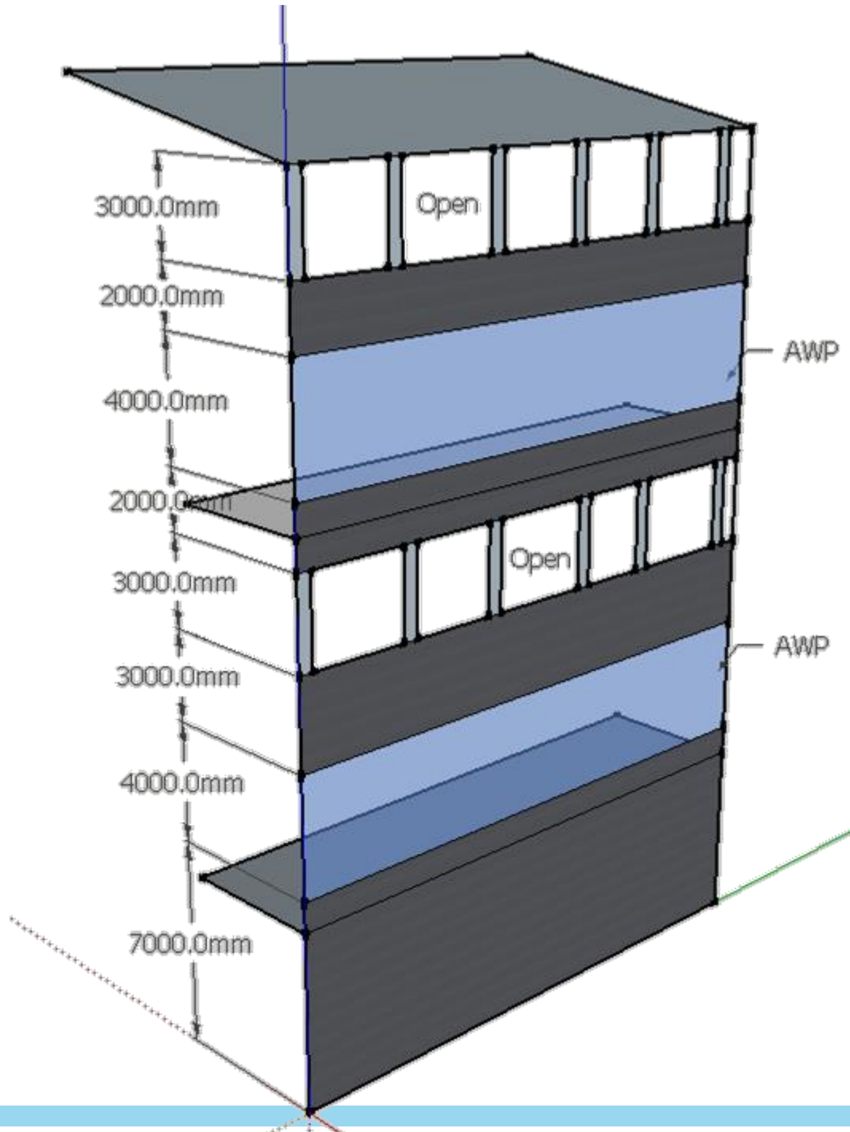
- Part of wall has AWP
- Total opening degree is important
- Combination of open, closed and AWP



How AWP can operate / different strategies

- Open on gas detection
  - Often too late to reduce gas cloud
- Automatic operated based on wind and temperature, snow and ice:
  - Open at good weather
  - Close when people are present and weather is bad

Recommendations – Wall designs



- Additional Ventilation where required
  - Higher levels where buoyant release accumulates
  - Alteration to roof opening design to allow more gas to escape
  - Not frequently manned areas
- More Control where required
  - Active weather panels positioned at working heights on lower and upper deck
  - Allows control of wind speed where people will be working
  - Automatic opening during low wind speeds and high temperatures
- Pop Out blast panels
  - Can significantly reduce explosion pressures

LQ, helideck, utility and process location on FPSO

- LQ and helideck upwind to avoid
  - Smoke
  - Exhaust
  - Turbulence
  - Gives poor ventilation to process
- LQ and Helideck downwind
  - Gives better ventilation to process modules
  - Must ensure long enough distance from process to LQ
  - Conflicts with aft offloading

SUMMARY AND RECOMMENDATIONS

Recommended measures

- Layout and process recommendations
- Personal protective wear and equipment
- Temporary windbreaks or active wind walls
- Procedures and operation – Work restrictions, "Cold permit"
- Information, coursing and medical preparedness
- Access to heated shelters close to cold working areas

Benefits of combined explosion and wind chill analyses

- Wind chill and explosion challenges identified in early project phase, and not later based on "bad" experiences
- Difficult or costly to implement improvement measures after early design phases
- Decision support for a safe and sustainable design and operation

Thank you!

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