# The use of CFD for the design of hydrogen bulk storage areas

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# Introduction

GEXCON

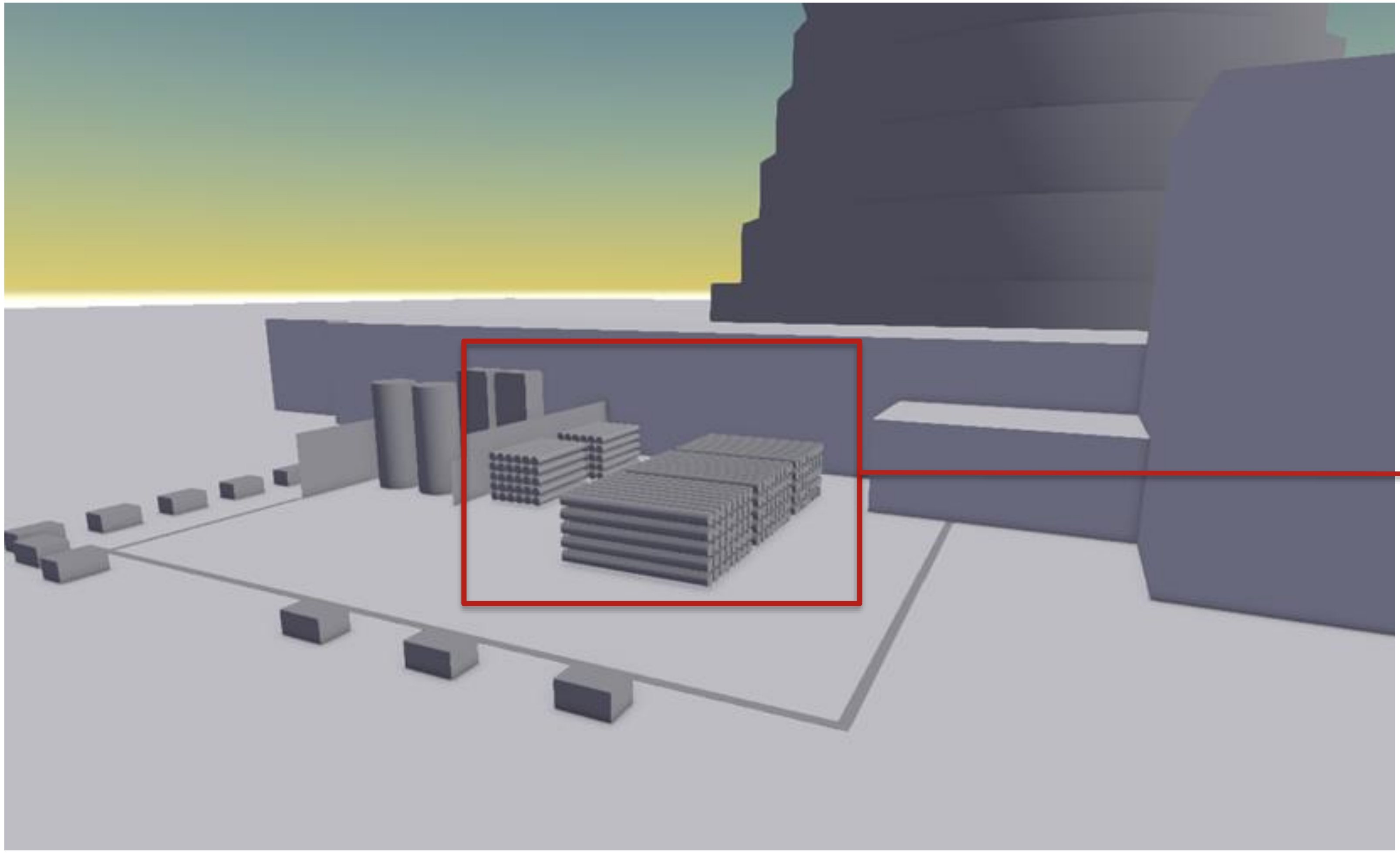
# Background

- A client from Gexcon uses Hydrogen as a coolant for their power generators. $H_2$ is stored at a pressure of up to 100 bar in multiple cylinders which are arranged in five bank installed in an external location in the vicinity of other occupied buildings.
- Gexcon were initially requested to provide an appraisal of a 2D explosion modelling study conducted by a third party and advise with regards to the validity of the conclusions made as part of the assessment.
- The assessment considered that a release of hydrogen from a 1'' diameter orifice could lead to a stoichiometrically mixed cloud of hydrogen and air with a volume of up to 400 $m^3$ within the hydrogen cylinder storage area.
- The likely overpressures yielded from an ignited event considering a hydrogen cloud of this size would be significant enough to affect an occupied 'target building' in the surrounding area with estimated overpressures of 13 barg using TNO Multi-Energy Method.
- Gexcon was then requested to perform detailed explosion simulations using FLACS CFD in order to estimate the expected maximum explosion overpressures and the likelihood of DDT occurring from an unconfined gas explosion, using the 400 $m^3$ gas cloud previously determined.

# Modelling strategy

# Geometrical model

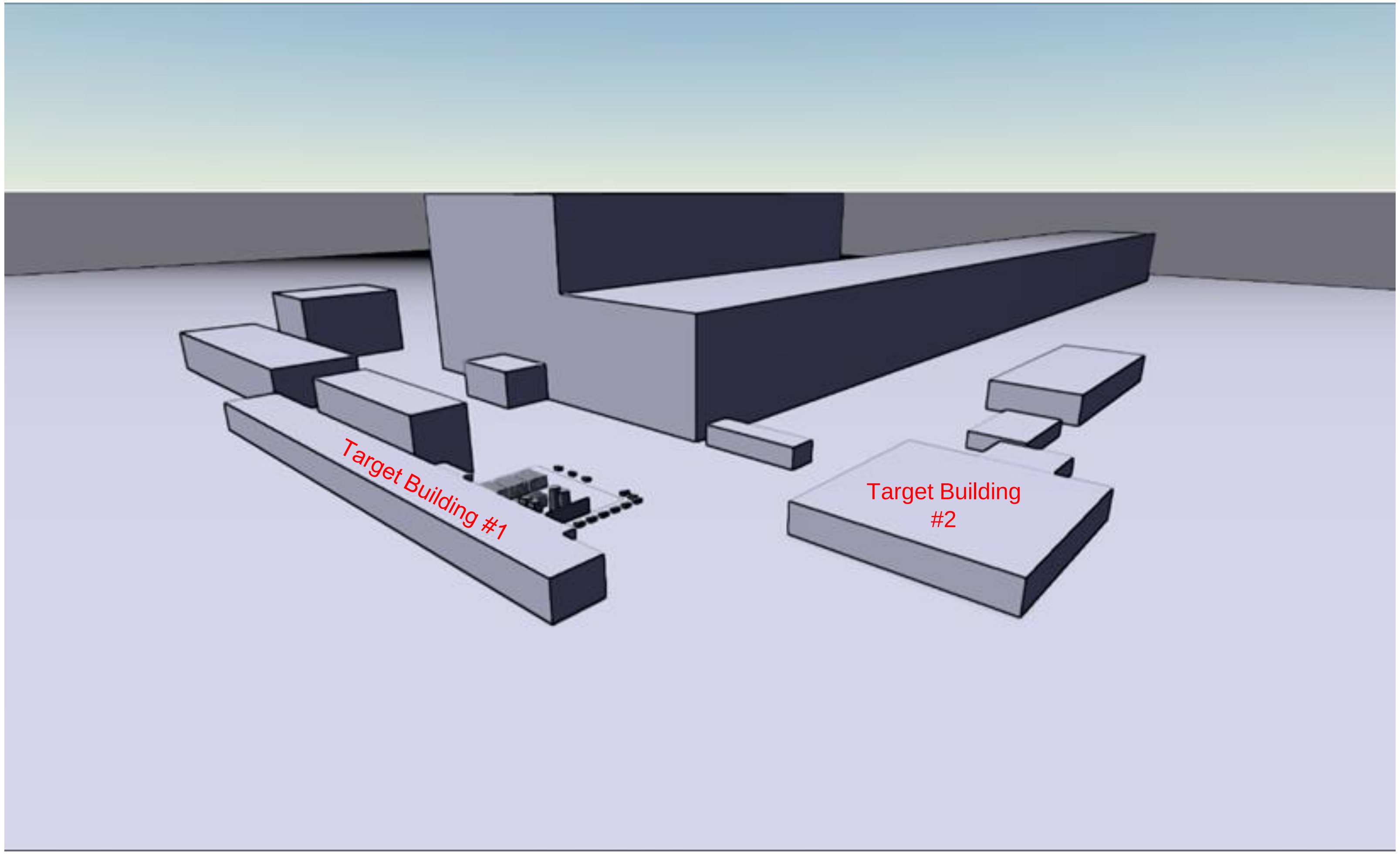
## (Hydrogen cylinder banks shown within the red box)



Example of hydrogen cylinders bank

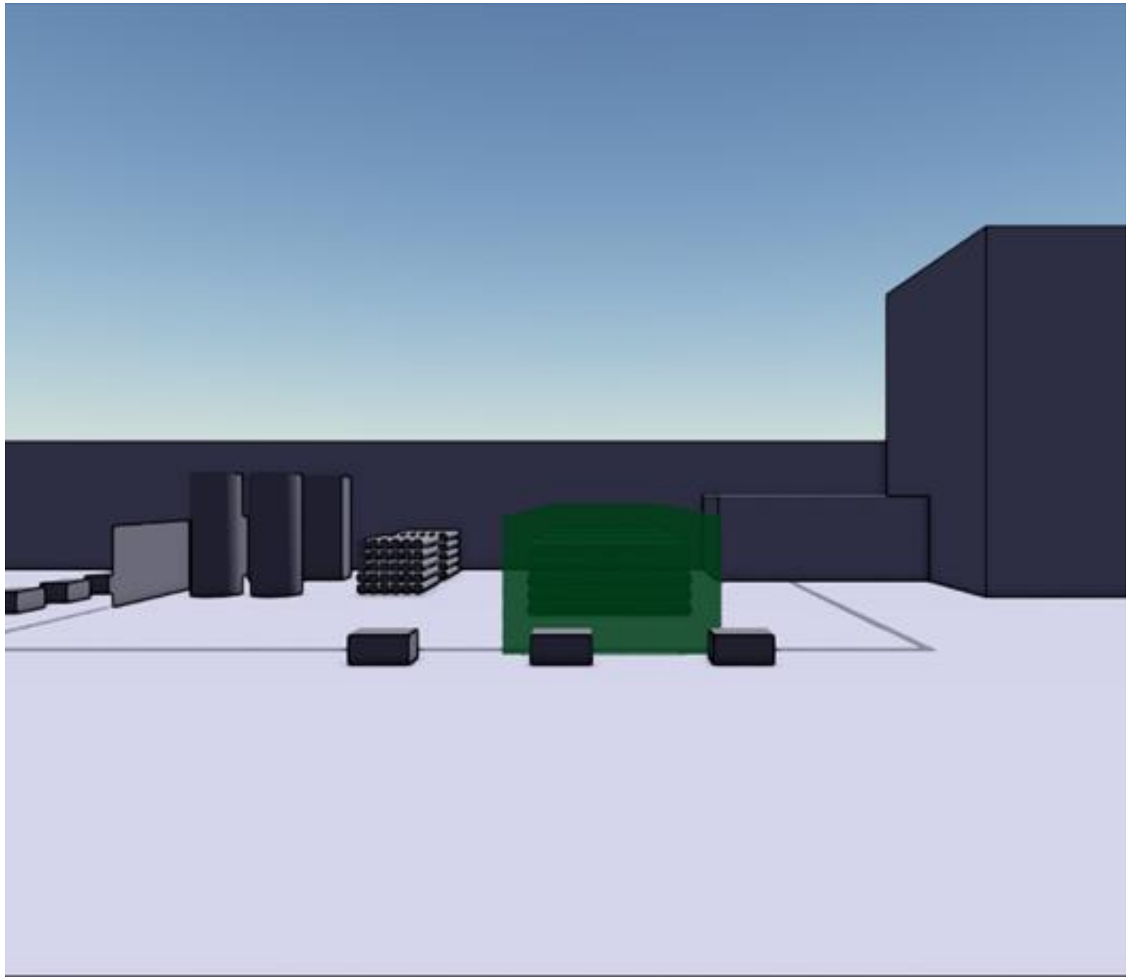
# Geometrical model

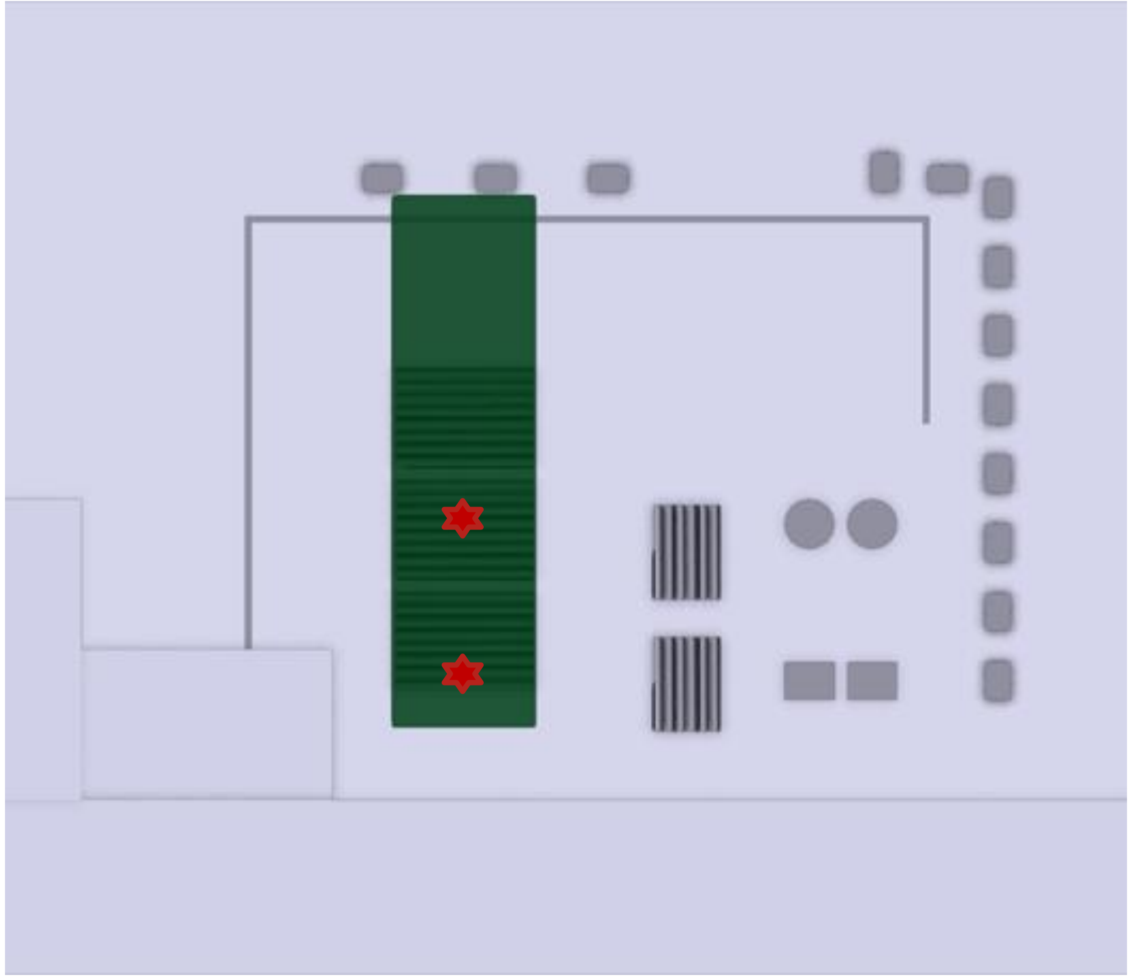
## (Surrounding area)



# Gas cloud configuration and ignition locations

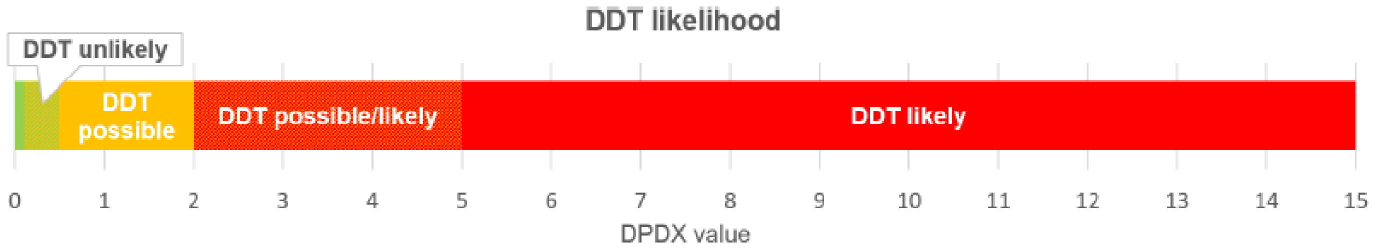
## Stochiometric 400 $m^3$ cloud of hydrogen





# DPDX and DDTLS definitions

- Gexcon develops the dedicated CFD tool FLACS-Hydrogen for hydrogen safety applications. FLACS-Hydrogen has been commercially available for more than 10 years.
- FLACS-CFD is able to give an indication of the likelihood of deflagration to detonation transition (DDT). While FLACS-CFD cannot model DDT directly, functionality has been developed that uses parameters DPDX and DDTLS to provide indication of the phenomena occurring.
  - DPDX is a measurement of the normalised spatial pressure gradient across the flame front, which indicates when the flame front captures the pressure front, which is the case when DDT occurs.

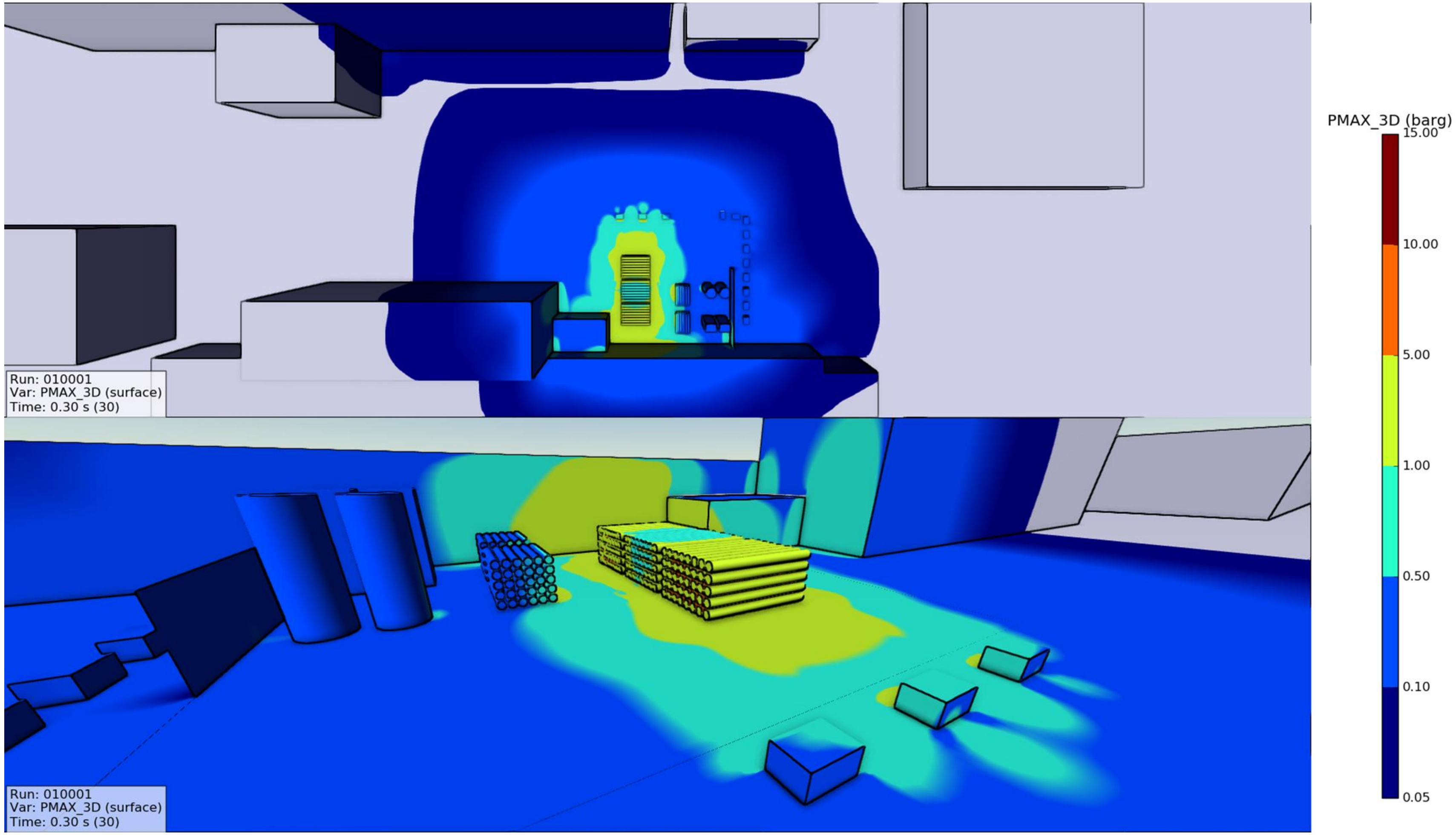



  - At the same time, the flame front also has to cover a large enough area compared to the detonation cell size of the gas (approximately 1 cm for $H_2$). The DDT Length Scale ratio (DDTLS) is defined as the quotient of the characteristic geometrical dimension (LSLIM) and the detonation cell size $\lambda$

# Preliminary results

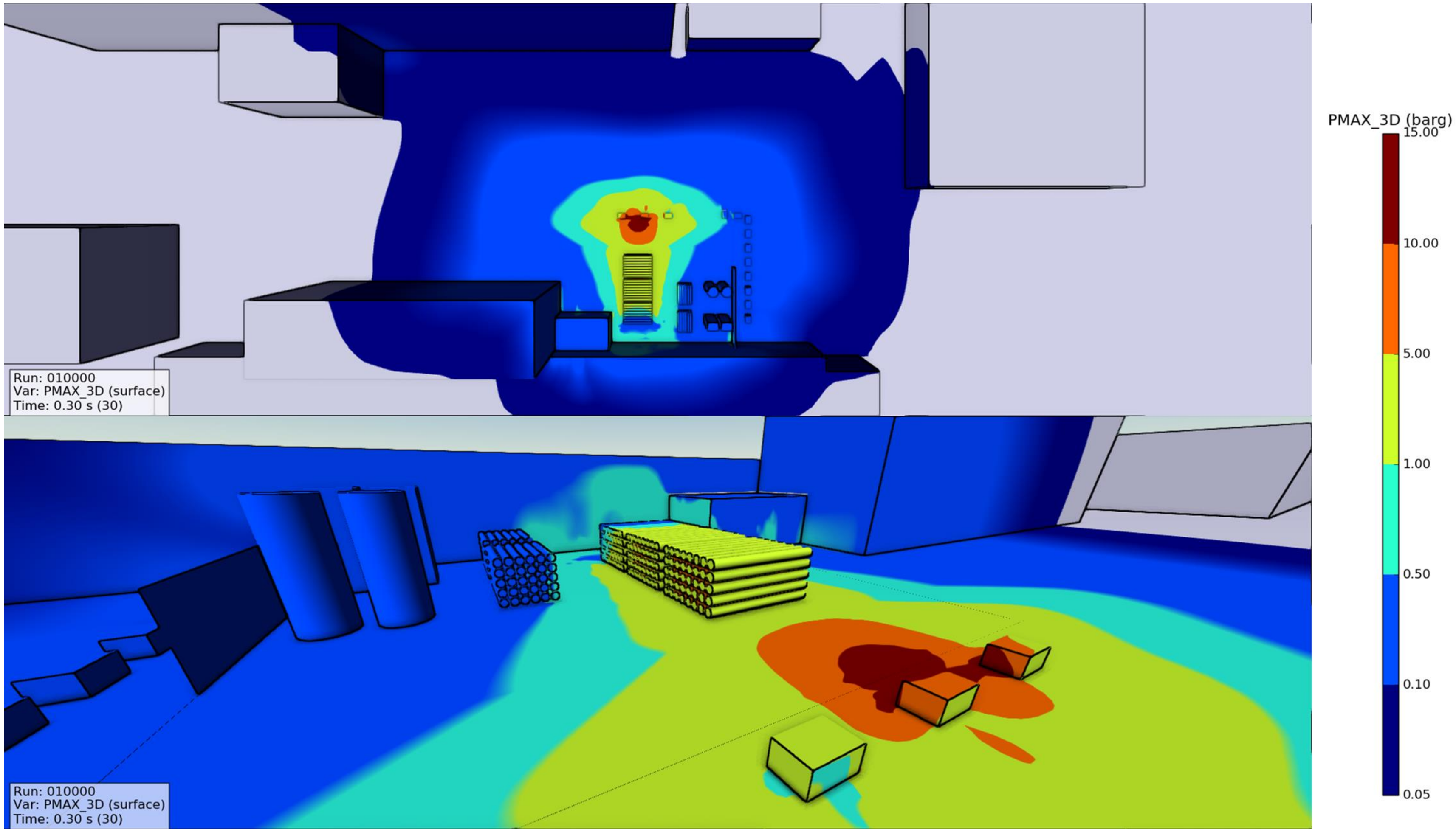
# Maximum predicted overpressure

## Central Ignition



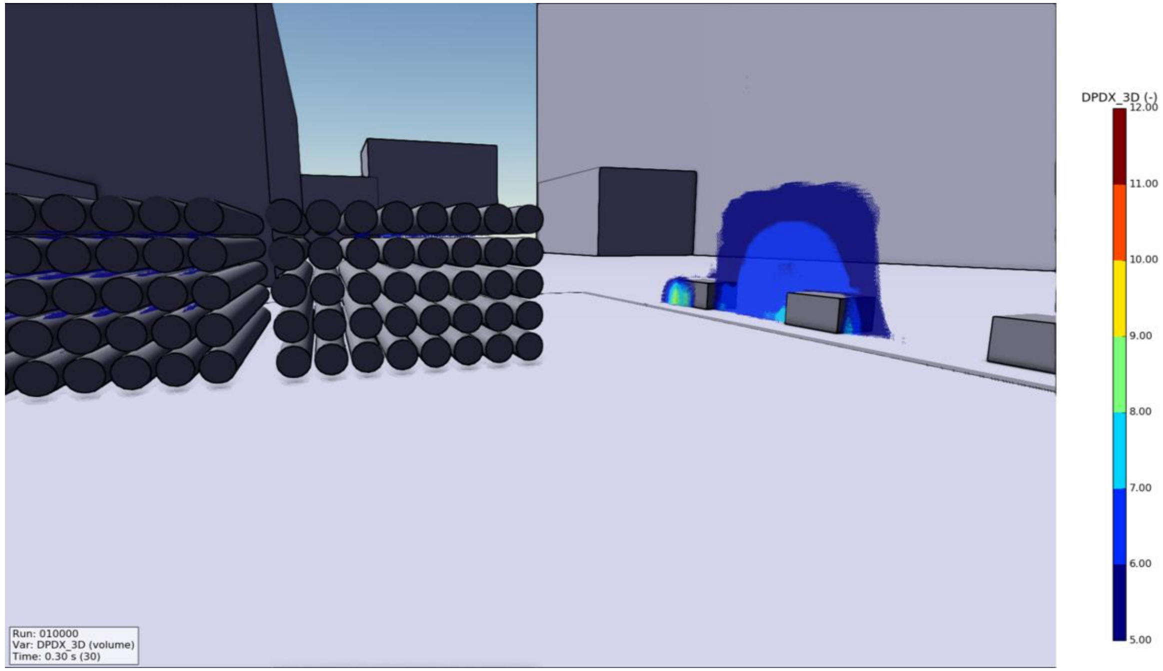
# Maximum predicted overpressure

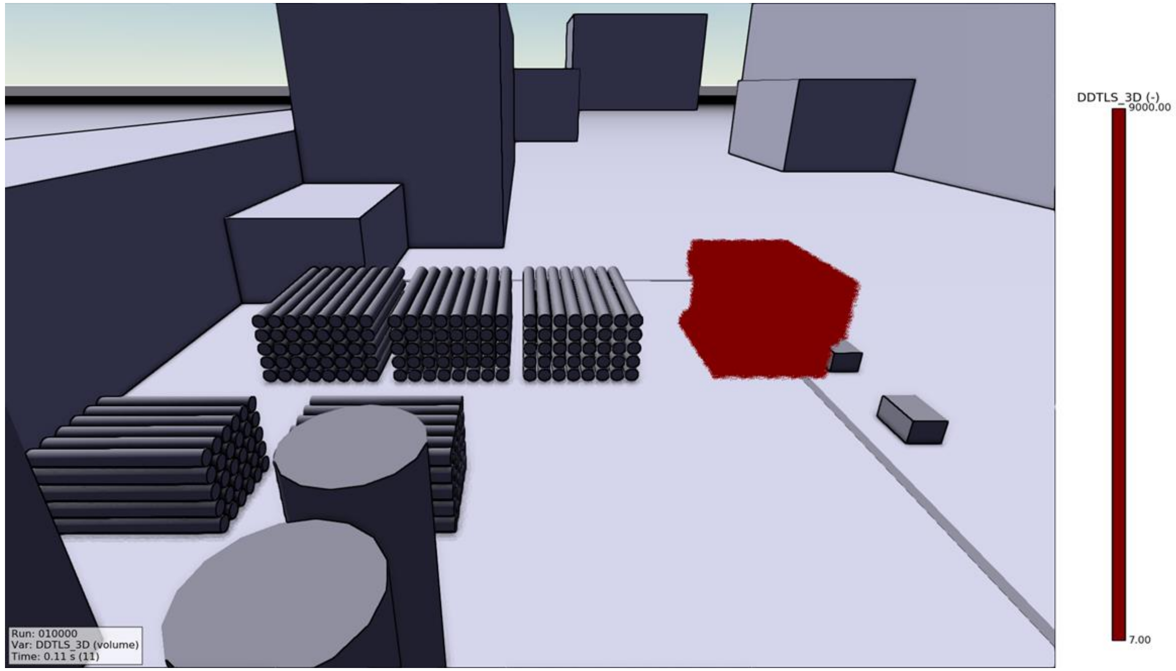
## Corner Ignition



# DDT and DDTLS predictions

## Corner Ignition



# Preliminary results

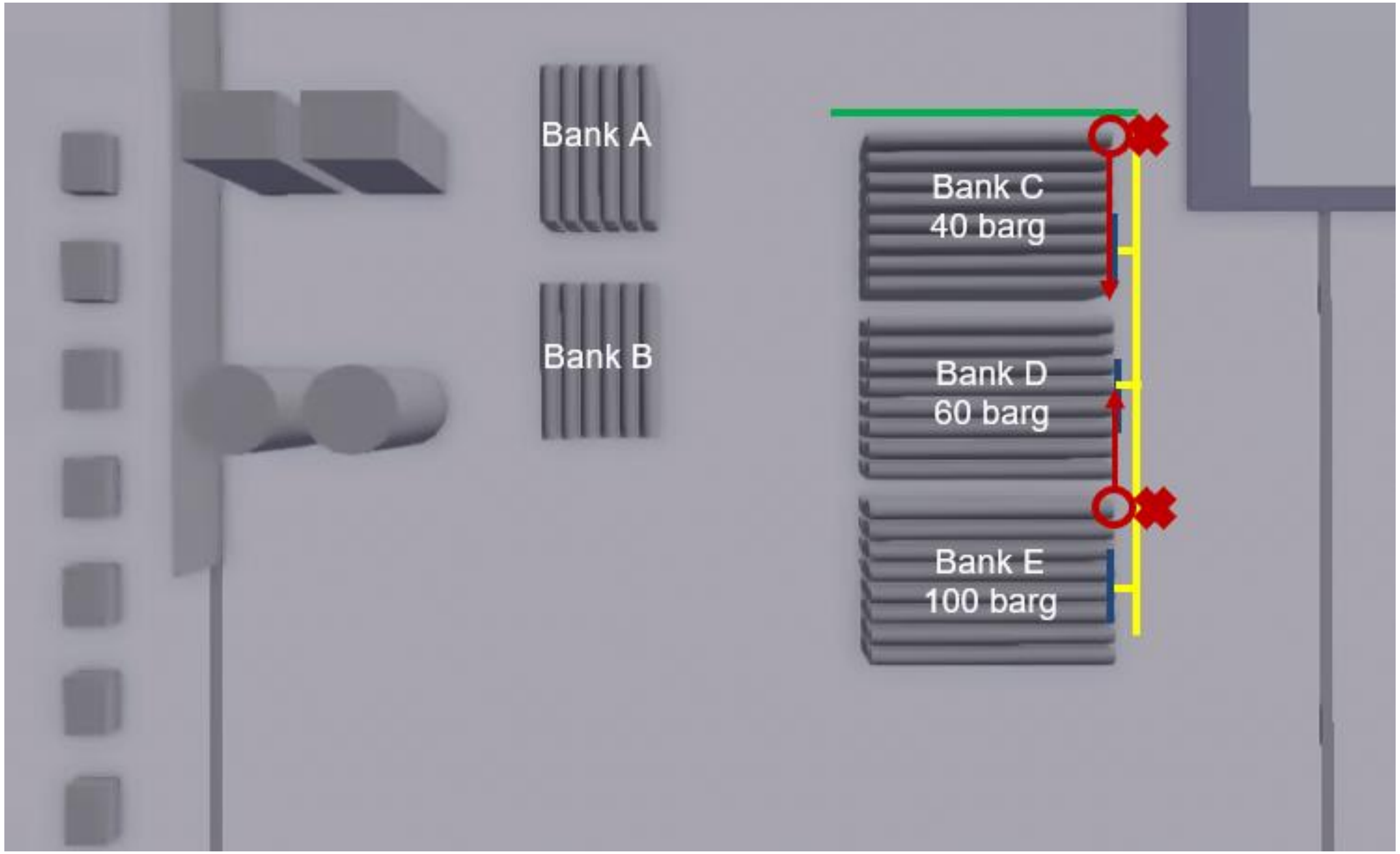
- It was identified that for both scenarios tested (centre and corner ignitions) a deflagration to detonation transition (DDT) could potentially occur in the event of an explosion under the conditions tested. Consequently, the resultant overpressures in the event of a detonation could reach magnitudes in excess of 10 barg.
- Gexcon's initial opinion was that the assumptions considered were overly conservative, particularly about the maximum flammable gas cloud size to be considered (~400 $m^3$). This leads to potentially unrealistically high explosion overpressures affecting surrounding still likely to result in the collapse of the walls of the building buildings (e.g., target building #1, down to 4 barg from 13 barg initially predicted by TNO).
- It was therefore recommended by Gexcon that detailed dispersion modelling should be conducted in order to obtain a more realistic indication of:
    - the flammable gas cloud size and,
    - resultant overpressures following ignition of an accidental release.

# Extended modelling

## Dispersion and Explosion studies

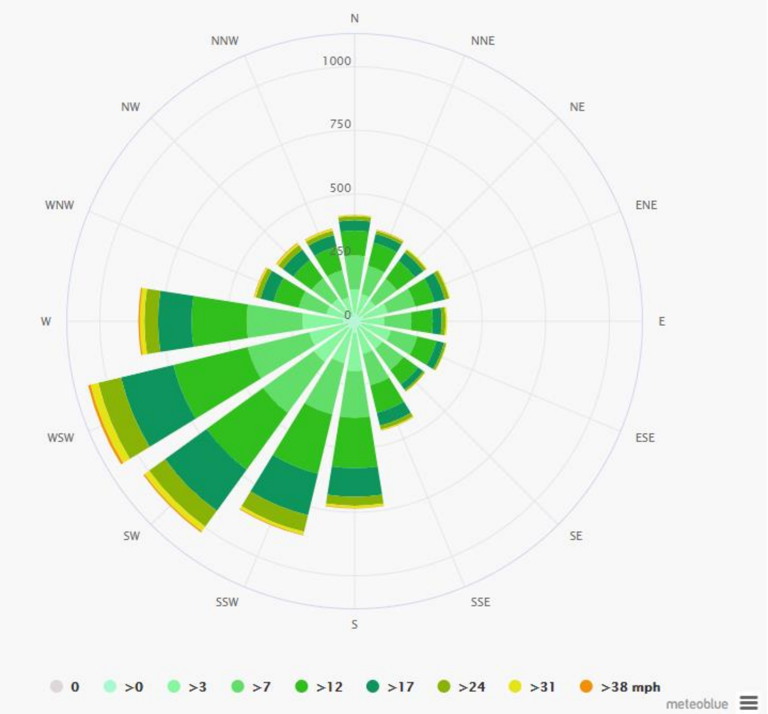
# Release modelling

## Leak location and directionality (red circle and arrow respectively, ‘X’ downward direction)



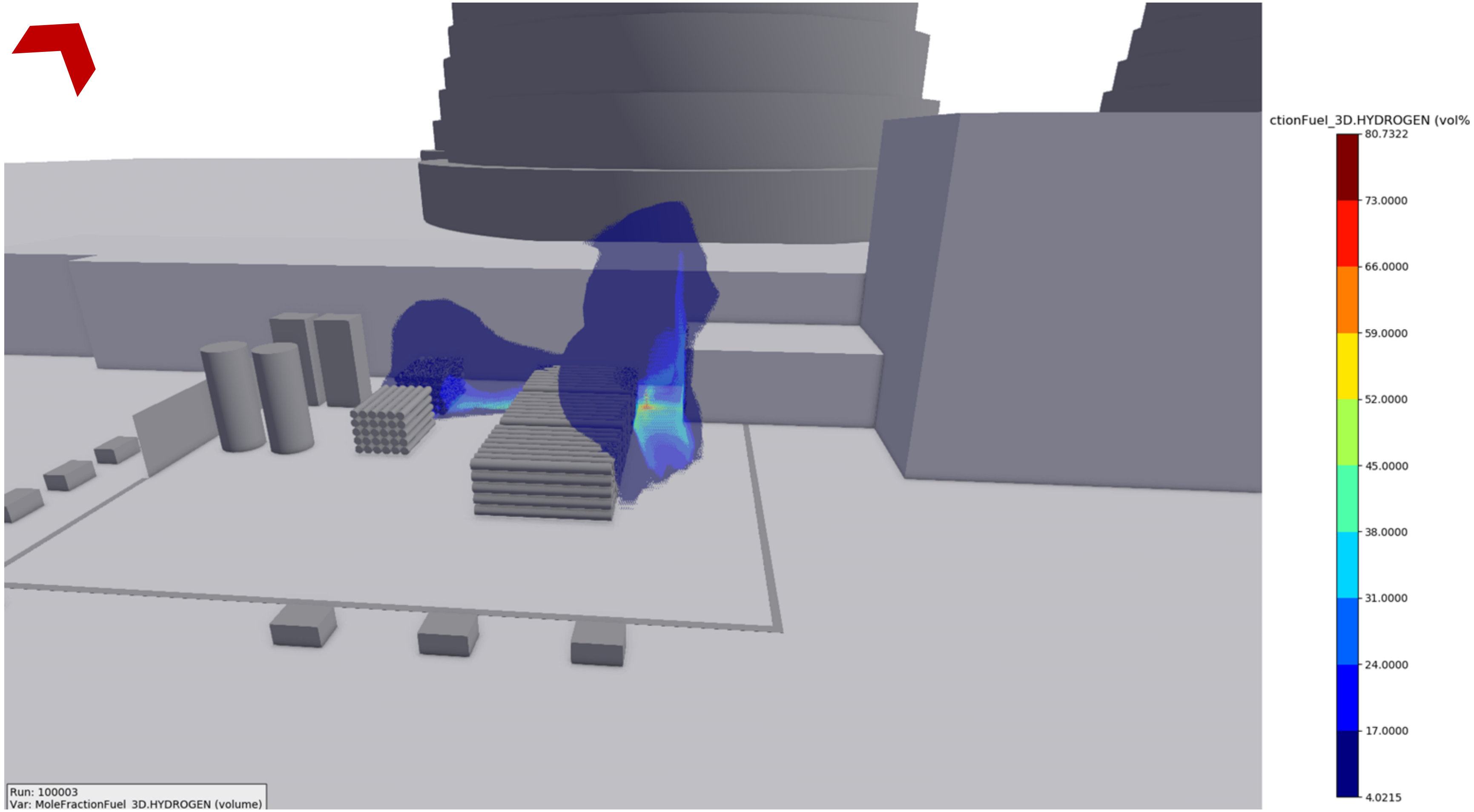

Failure of the connection in the shared line and the shared line between individual cylinders.

Hole size approximately 1” in size



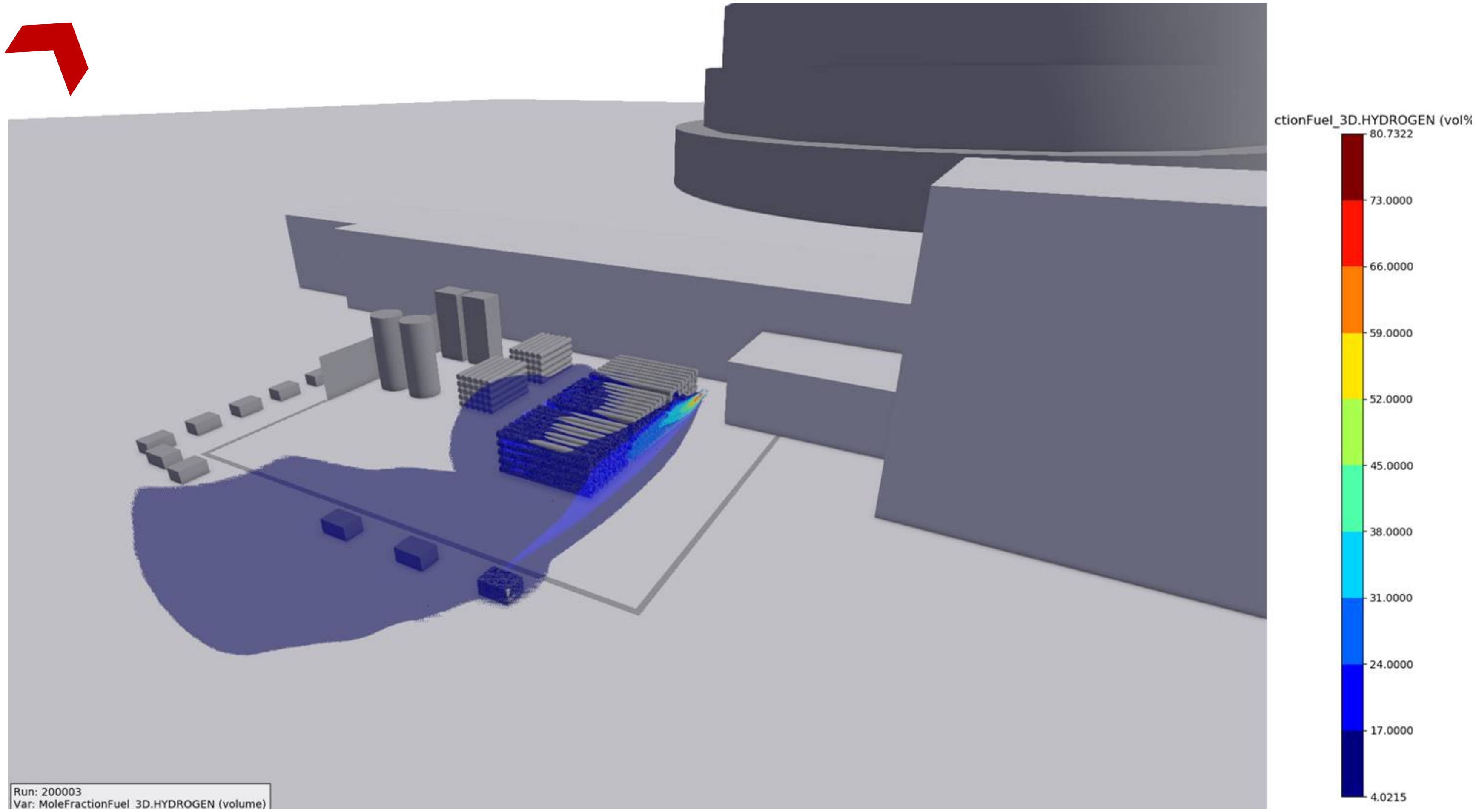
# Release modelling 1 - Bank C Downwards

## 5m/s WSW wind direction (red arrow)



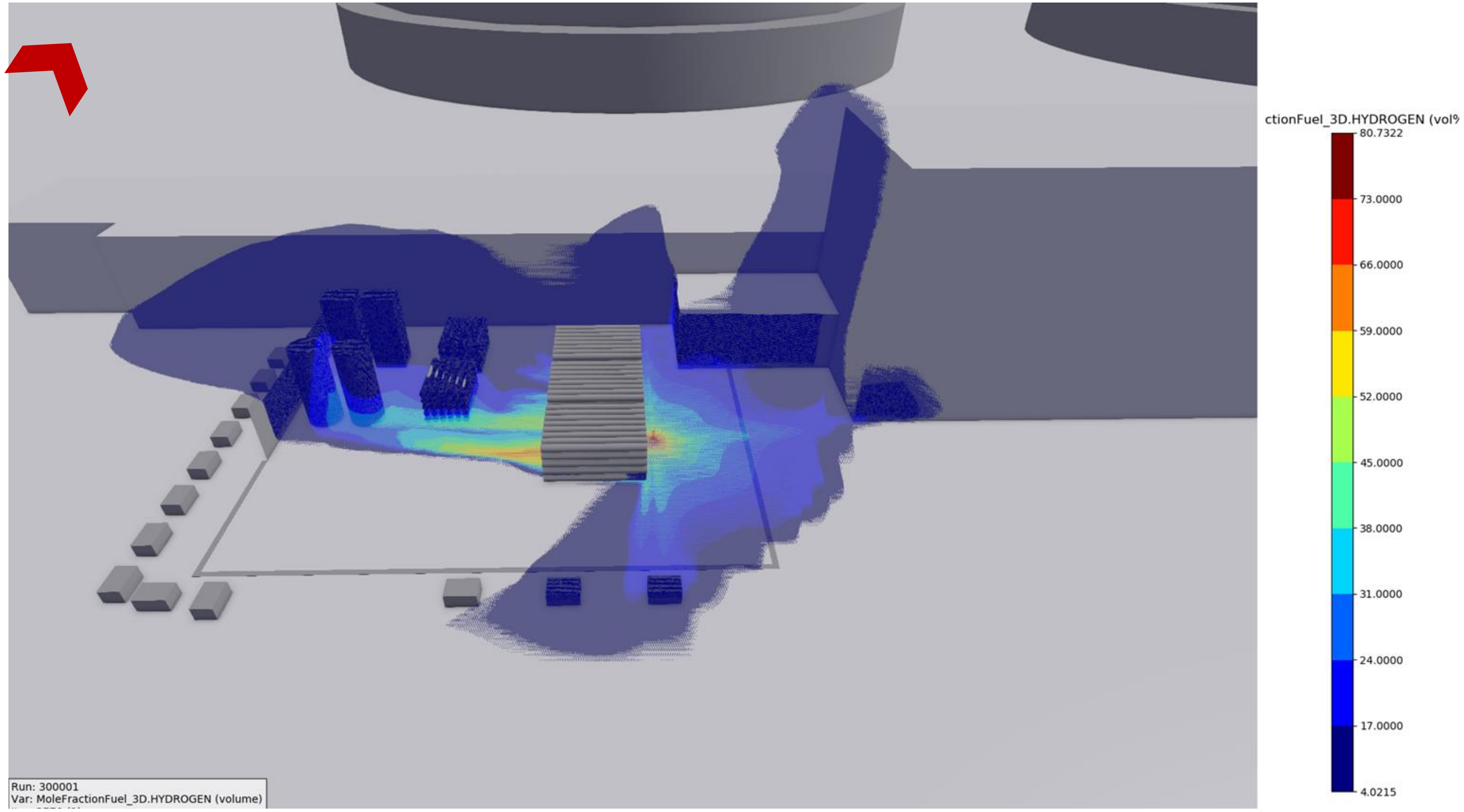
# Release modelling 2 - Bank C Away From Target Bldg. #1

## 5m/s WSW wind direction (red arrow)



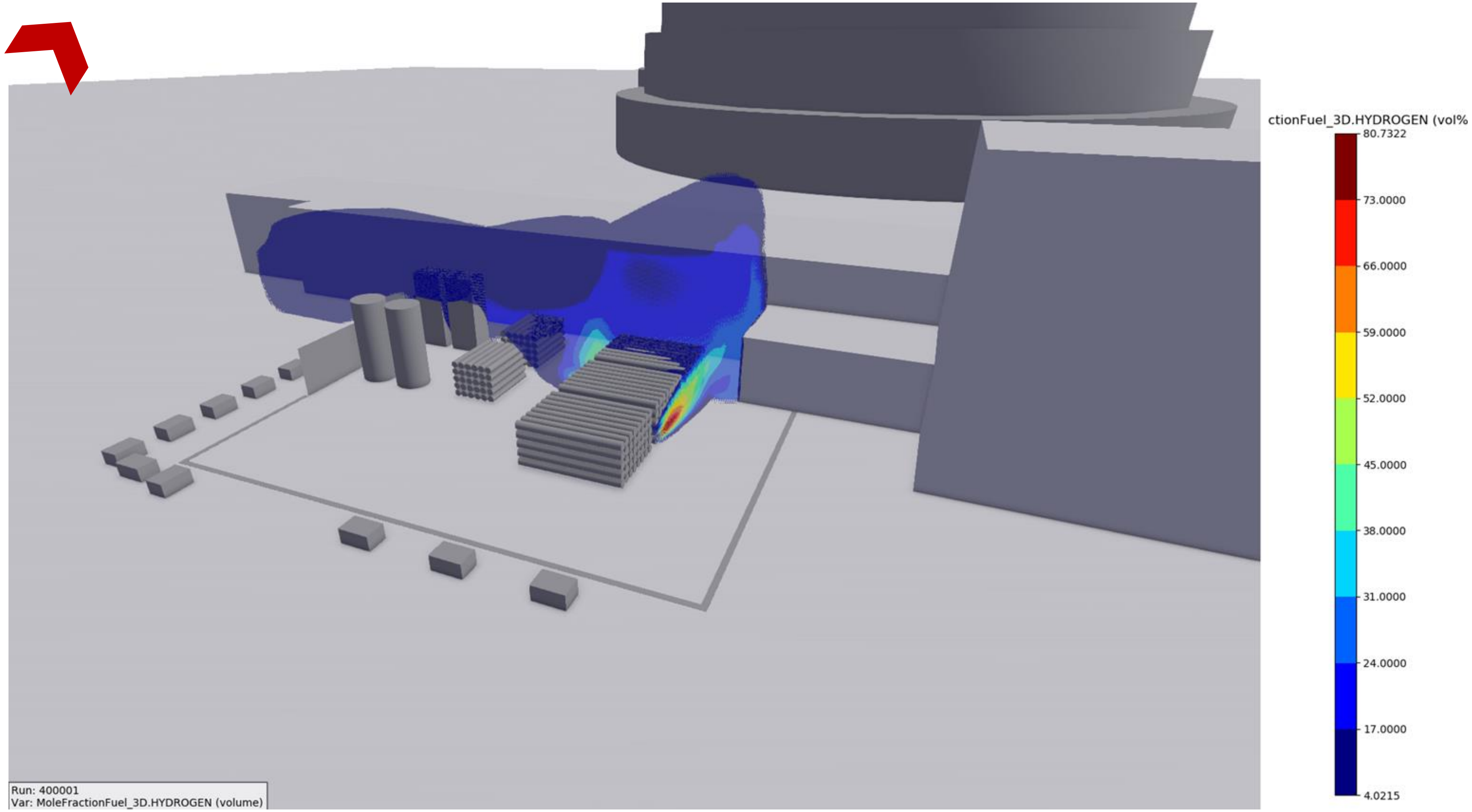
# Release modelling 3 - Bank E Release

## 5m/s WSW wind direction (red arrow)



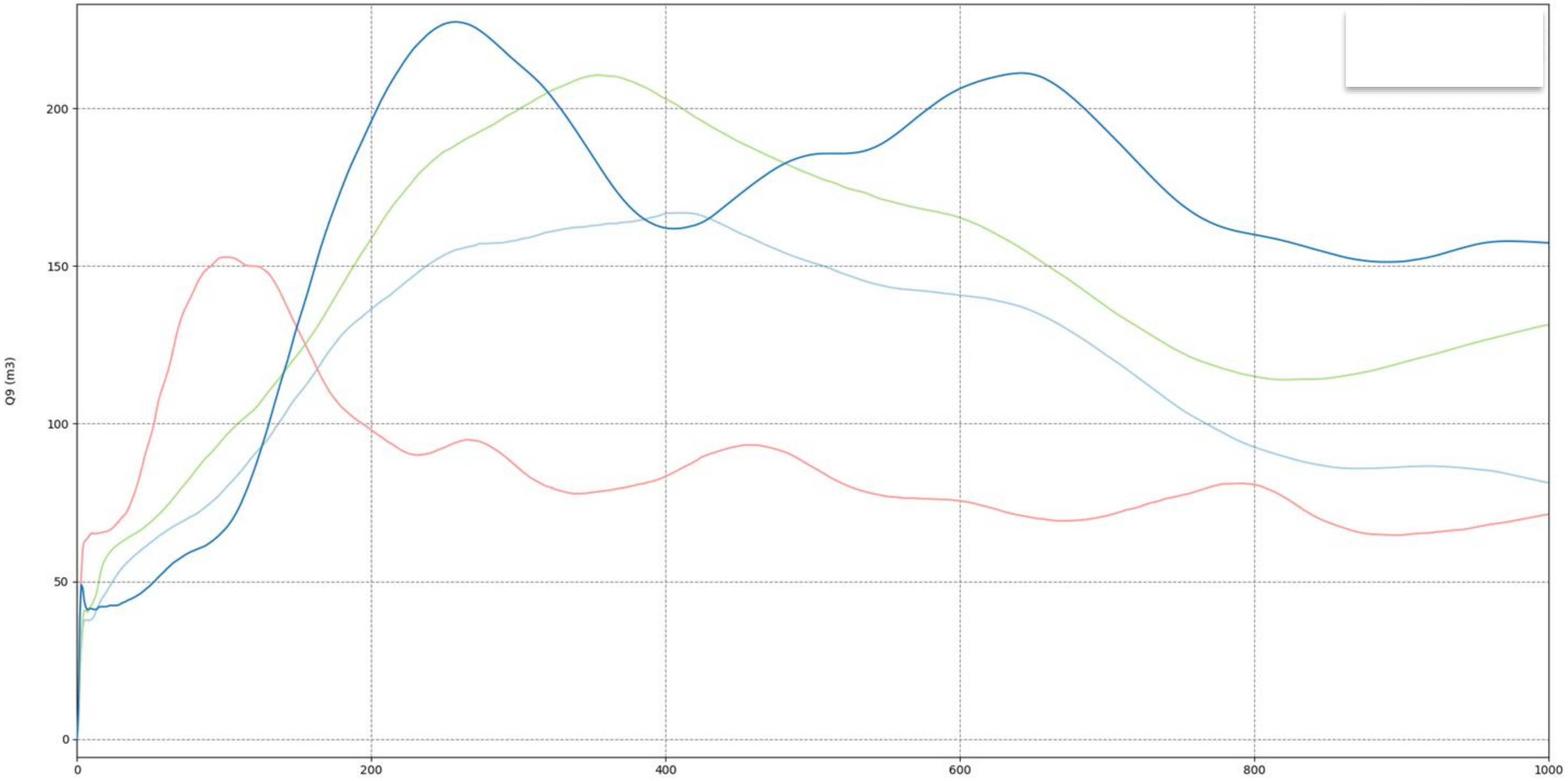
# Release modelling 4 - Bank E Towards Target Bldg. #1

## 5m/s WSW wind direction (red arrow)



# Dispersion Results

## Q9 flammable cloud volumes



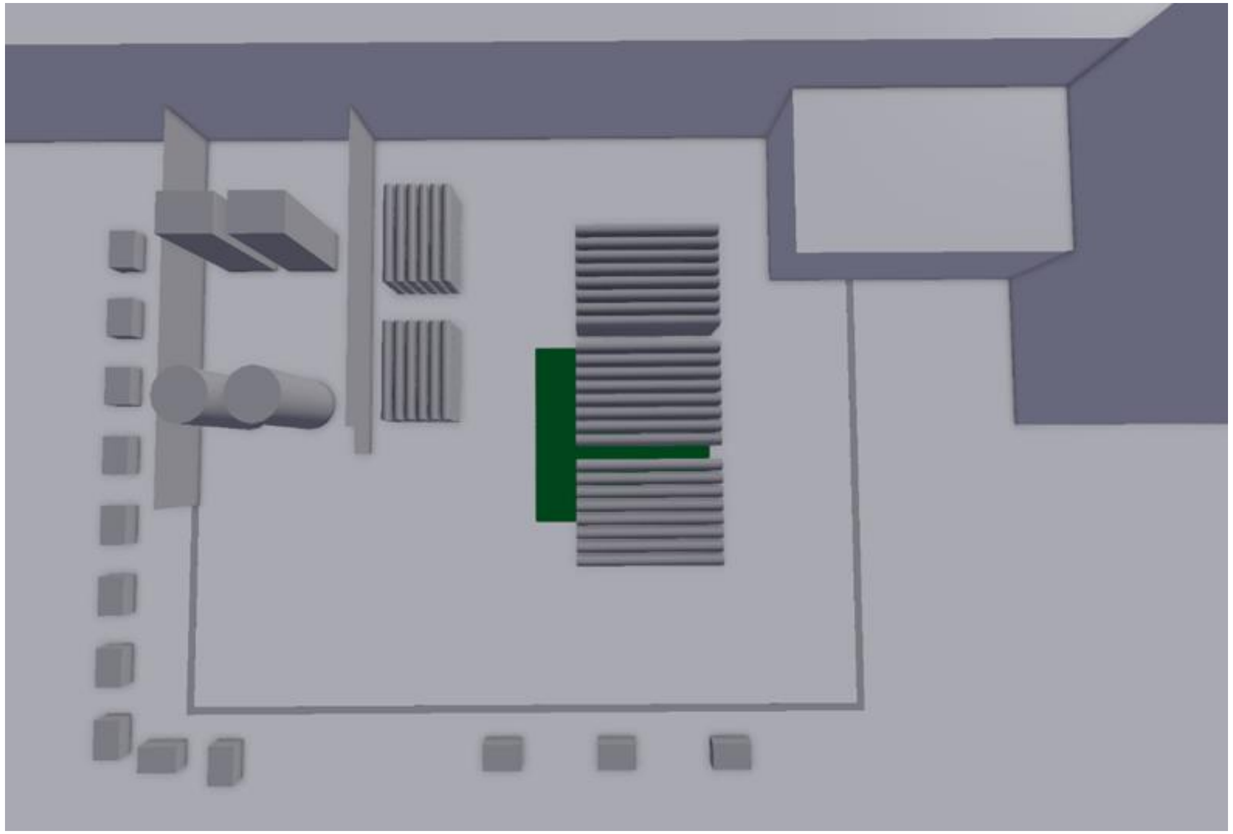

Q9 cloud is a scaled version of the non-homogeneous gas cloud where it has been converted to a smaller equivalent stoichiometric gas cloud that is expected to give similar explosion loads as the original cloud.

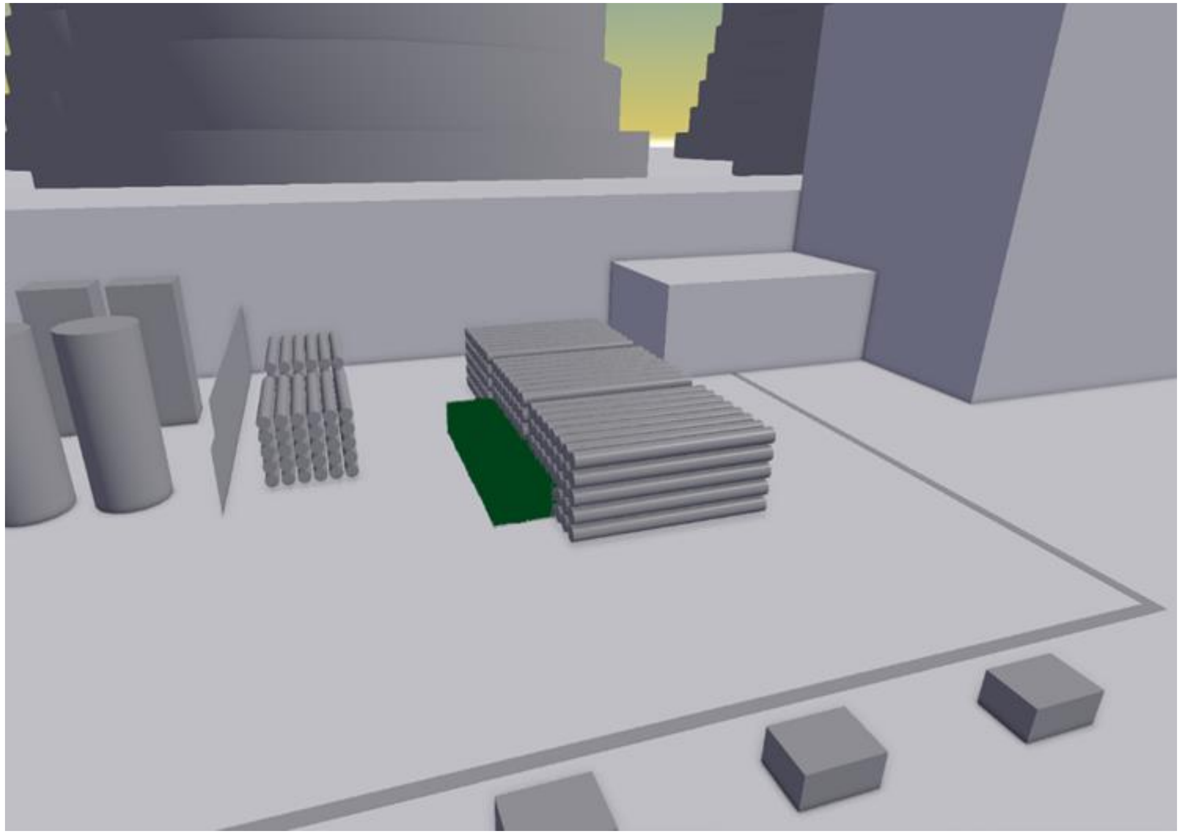
The monitoring region chosen to obtain the Q9 volume was a box extending around all of the hydrogen banks and extending up to the top of the target building #1.

The maximum Q9 cloud sizes obtained (from largest to smallest) are approximately **160, 130, 75 and 60 m$^3$**

# Explosion Results

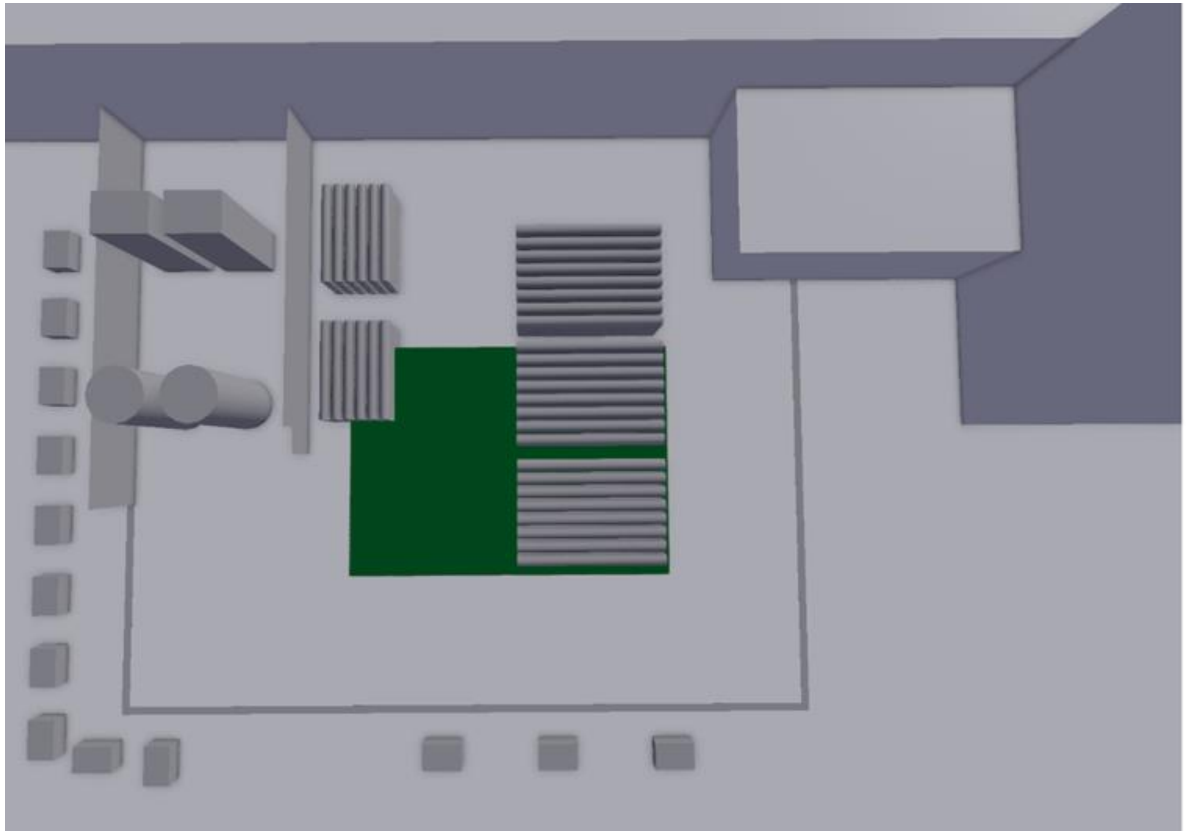
## Gas cloud representations - 1

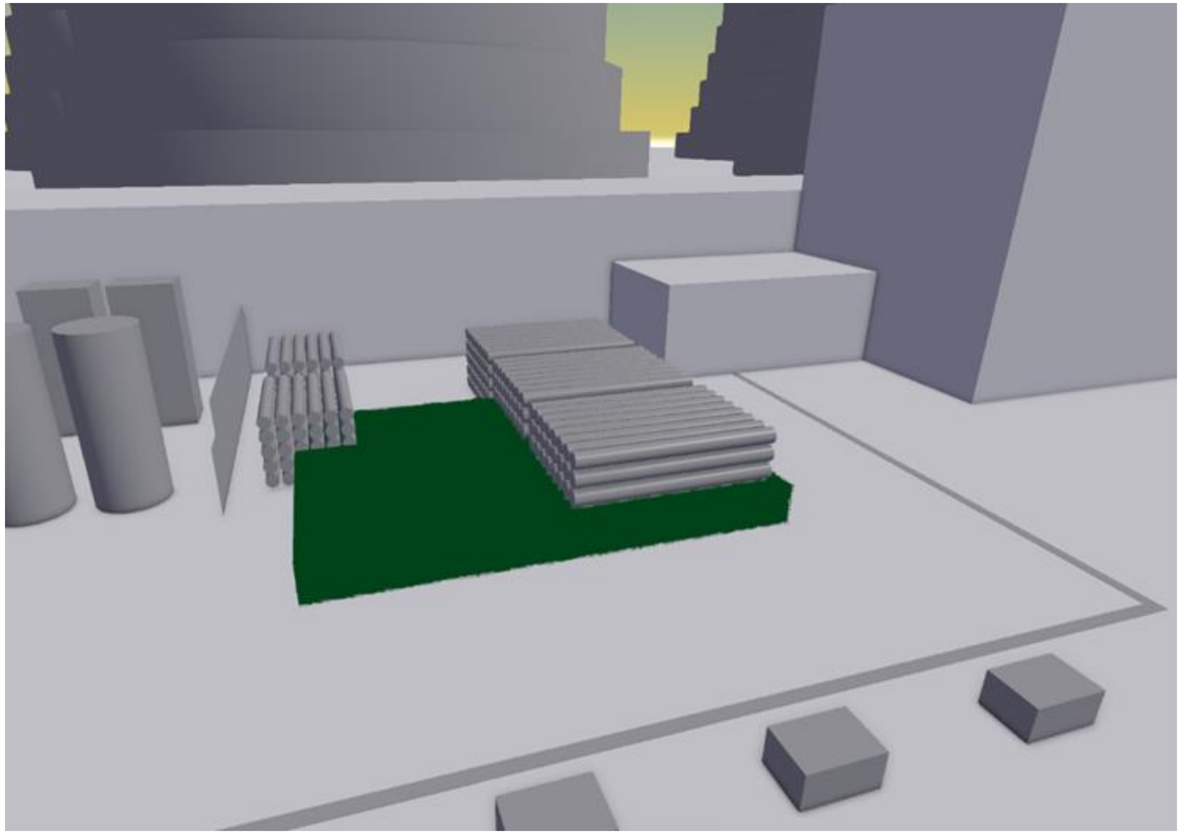




# Explosion Results

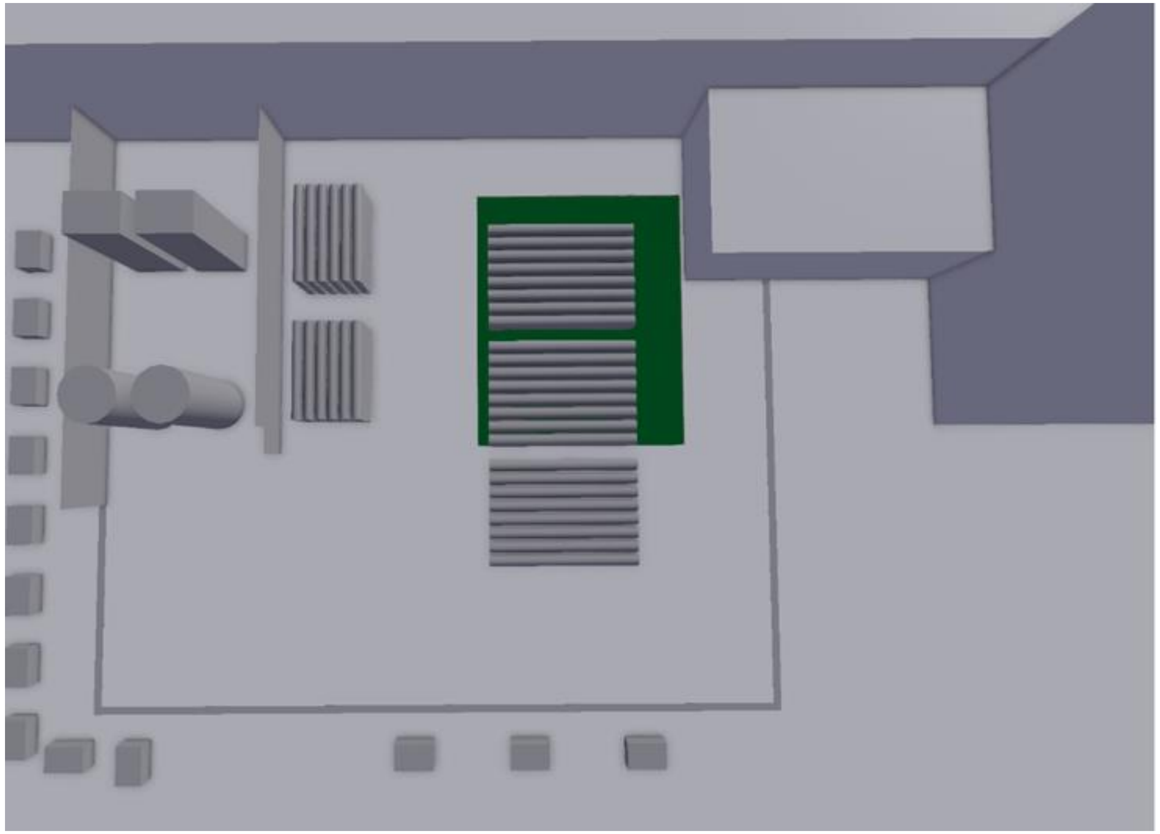
## Gas cloud representations - 2

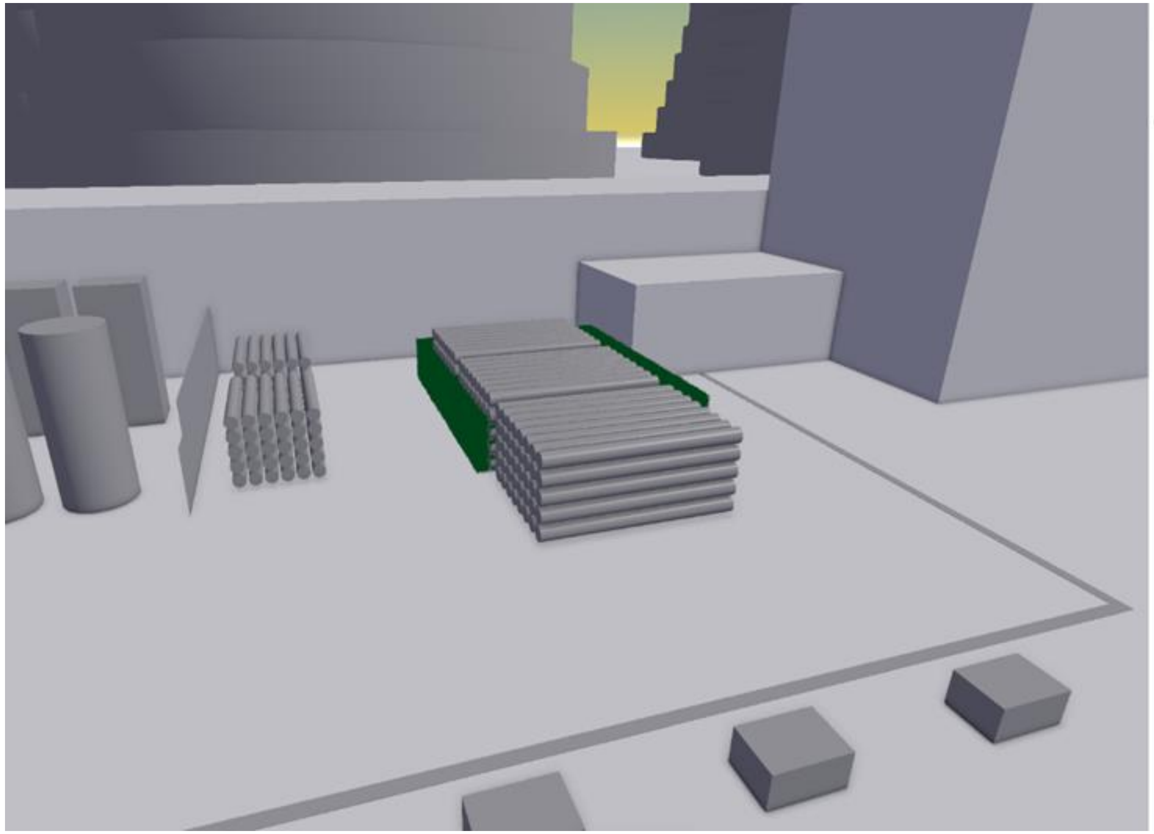




# Explosion Results

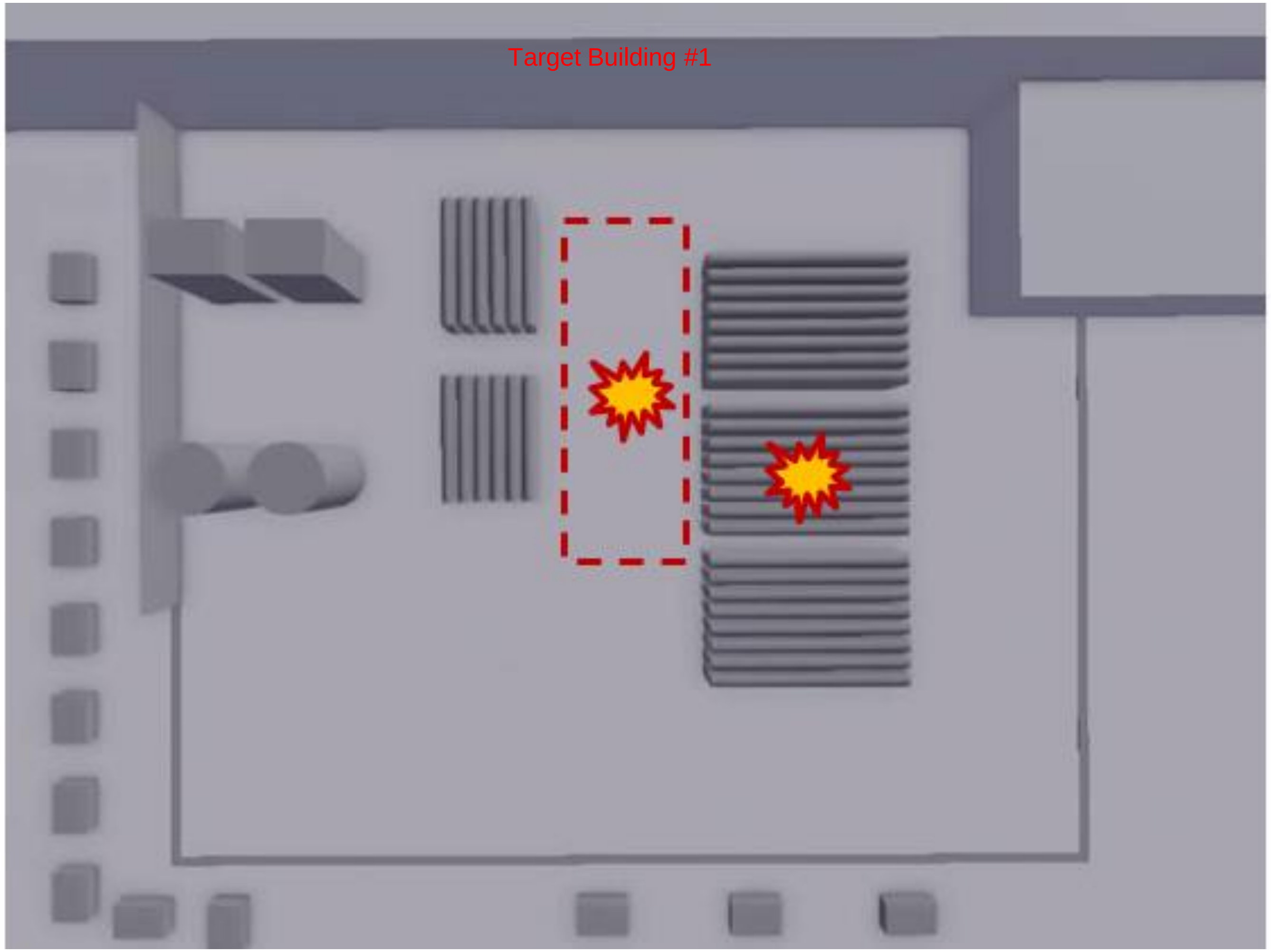
## Gas cloud representations - 3





# Explosion Results

## Ignition locations

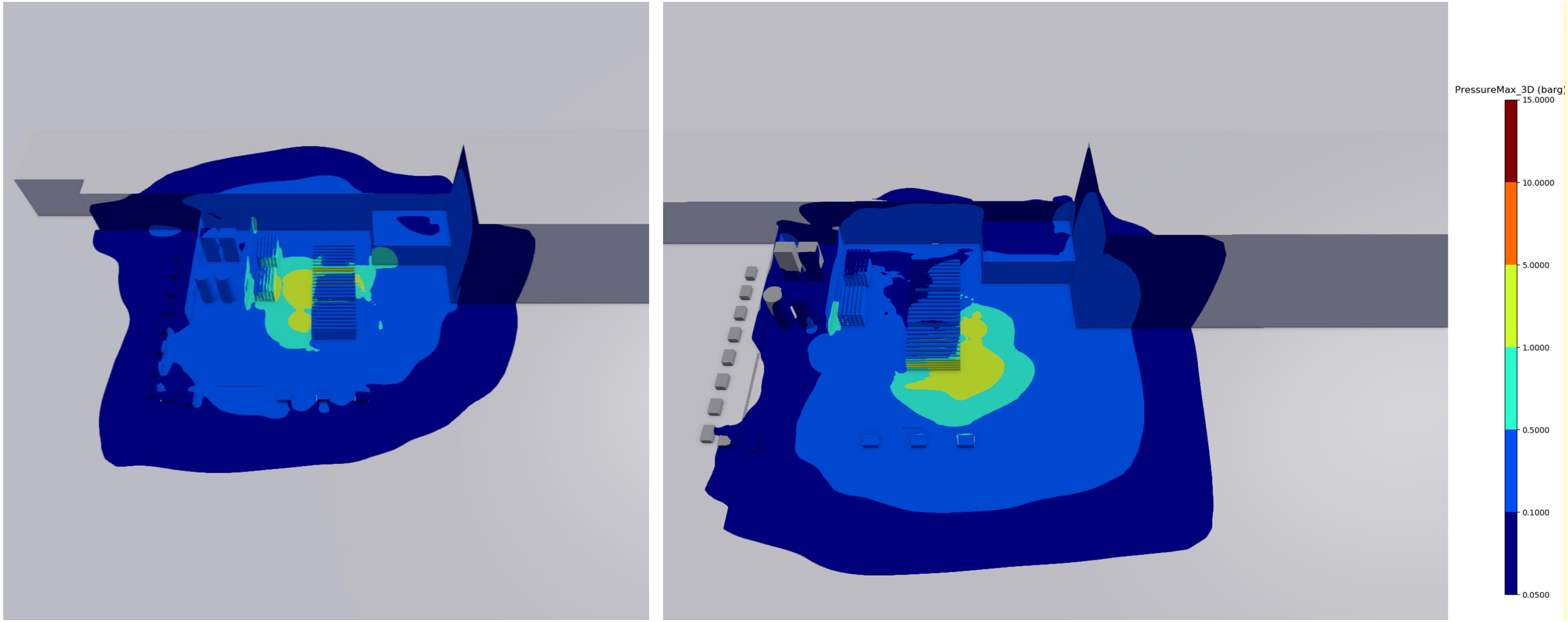



The first ignition location was chosen so that both the longest flame path across the cylinder banks and towards the target building #1 was achieved, meaning the most conservative position in terms of flame acceleration and consequently the highest overpressures.

The second ignition location was chosen to placed in the region of the tanker offloading area (dashed). This is thought to be the most credible ignition location due to vehicle movement, potentially hot brakes etc. posing a risk for ignition within the cylinder storage area.

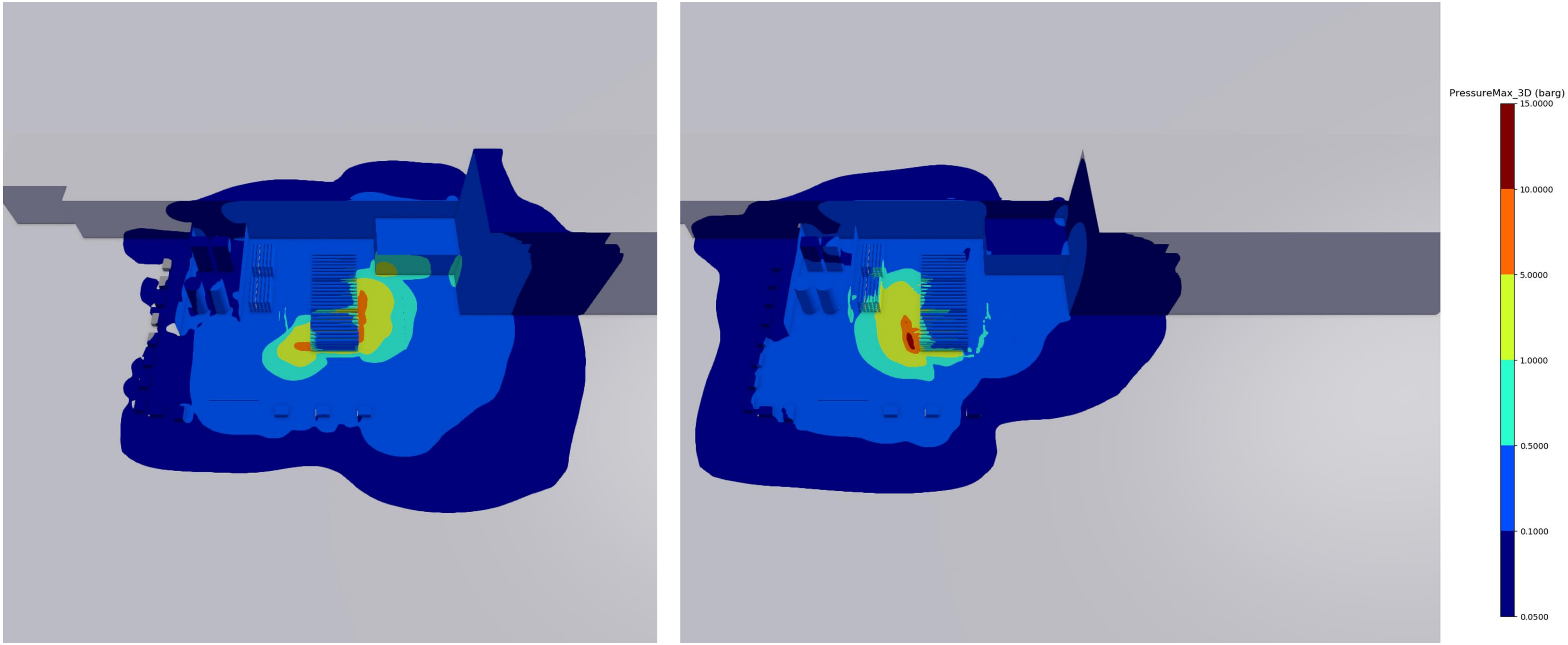
# Maximum predicted overpressure – Gas cloud 1

## Worst case and tanker offloading ignitions



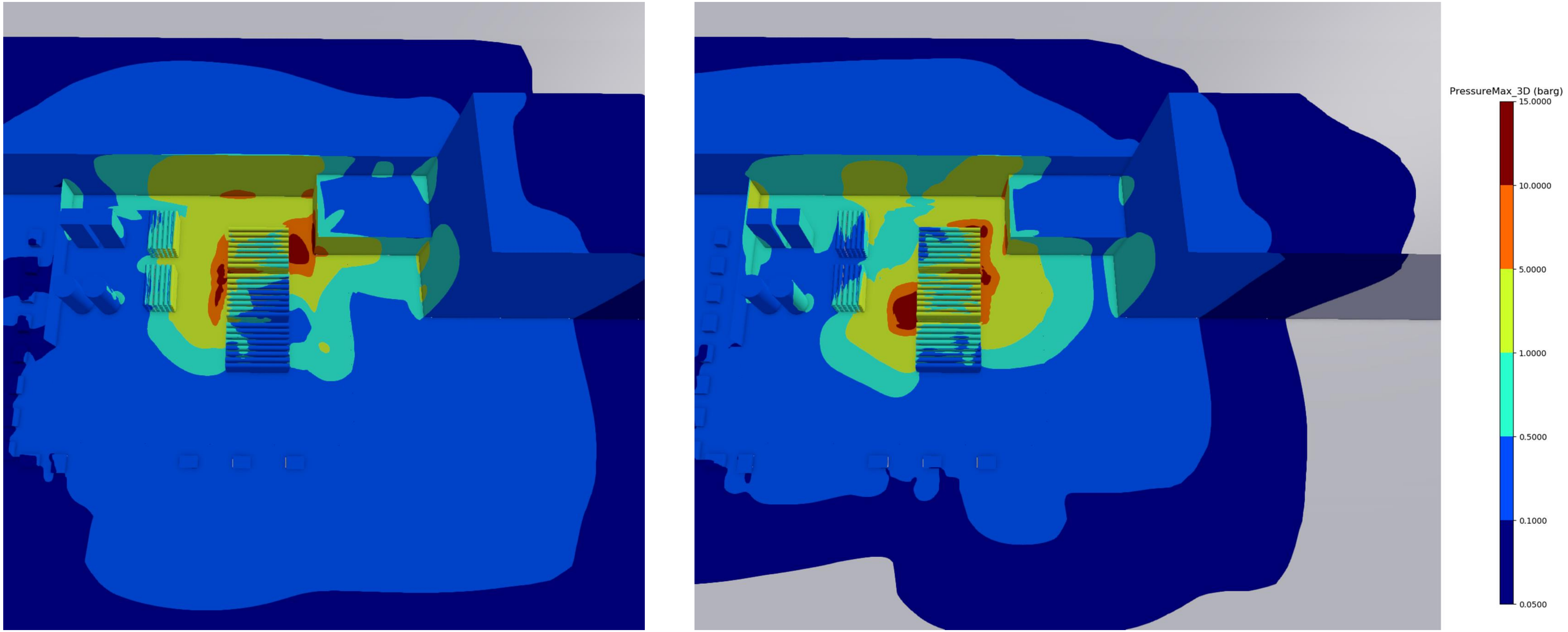
# Maximum predicted overpressure – Gas cloud 2

## Worst case and tanker offloading ignitions



# Maximum predicted overpressure – Gas cloud 3

## Worst case and tanker offloading ignitions



# Conclusions

# Conclusions

- Details of the findings of several gas explosion simulations from gas dispersion analysis were shown in order to assess the maximum expected overpressures around an $H_2$ gas cylinder storage compound.
- Steady state dispersion simulations considering local ventilation conditions within the surrounding area were simulated in order to predict a more realistic flammable gas cloud.
- Explosion simulations were then conducted using the 3 largest Q9 flammable cloud sizes within the cylinder compounds, whilst taking into consideration 2 ignition locations (worst case flame path and tanker offloading locations)
- Resultant maximum stoichiometric gas cloud volume (approx. 160 m3) was significantly smaller than that predicted within the Original study (400 $m^3$). However, the maximum overpressure experienced within the cylinder area (10-15 barg) and on the Target Bldg. #1 (1-5 barg) remained within the same ranges.
- Main difference observed with the newly obtained gas clouds, was that the likelihood of a deflagration to detonation transition occurring was shown to be unlikely in these scenarios (only one scenario was found to indicate detonation was likely to occur).

| Study | Cloud Volume Considered [$m^3$] | Pressure Range in Cylinder Area [barg] | Maximum Pressure on Target Bldg. 1 [barg] |
|---|---|---|---|
| Original | 400 | 10-15 | 4 |
| Scenario 1 | 75 | 1-5 | 0.3 |
| Scenario 2 | 130 | 10-15 | 2.5 |
| Scenario 3 | 160 | 10-15 | 3 |

# Conclusions

- Although the potential dangers of the use and storage of hydrogen have been identified, there is currently only a small amount of guidance/standards for the design of these areas in terms of safety during an ignited event (e.g. COP CP33 – Bulk storage of gaseous hydrogen at users premises)
- While some separation distances to occupied buildings or other obstructions are provided in the standard, lack of information around recommended layouts or distances between banks of cylinders is provided.
- Based on the results obtained, it was possible to observe that due to the interaction of the combustion products and unburnt fuel ahead with the congestion in the area, increased turbulence levels and greater flame acceleration were obtained leading to high explosion overpressures even for the smallest gas cloud sizes considered.
- Further safety measures should be investigated such as the orientation of the cylinders (i.e. layouts) and safety gaps in between cylinders banks (i.e. locations). Levels of confinement/congestion should be investigated so as to avoid flame acceleration across a particular design.
- No clear indication of the separation of the cylinders in each bank is provided by a standard, and considering the small detonation distance for $H_2$, this should be further investigated so as to recommend a value that is likely not allowing DDT to occur.

# Questions?

Thanks for your attention!

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