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Computational Fluid Dynamics modelling in a complex EPC Project

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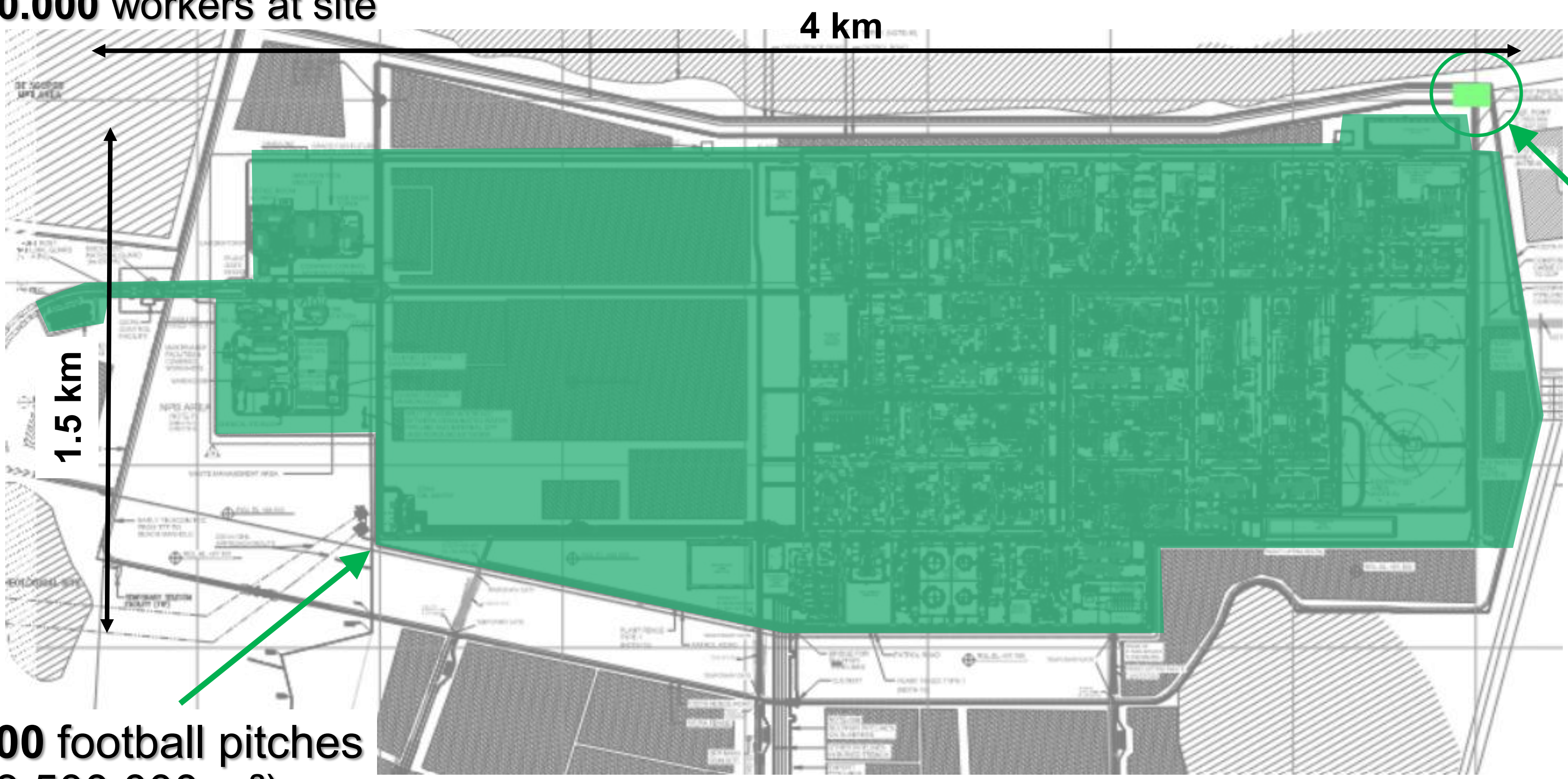
AGENDA

01	OBJECTIVES	WHAT THIS PRESENTATION IS ABOUT EPC CONTRACTOR'S PERSPECTIVE, TURNED TO PLANT OWNER PRACTICAL TIPS
02	CFD MODELLING IN A NUTSHELL	WHAT IS A CFD STUDY AND WHY DOING IT? HOW AND WHEN IS IT CARRIED OUT?
03	THE APPLICATION CASE	OVERVIEW OF PROJECT AND RISKS SELECTED CASES STUDY SET UP
04	THE STUDY OUTCOMES	ANALYIS RESULTS OF SELECTED CASES BENEFITS TO PLANT DESIGN
05	CONCLUSIONS	WRAP UP OF KEY CONCEPTS TAKE AWAY TIPS

Introduction

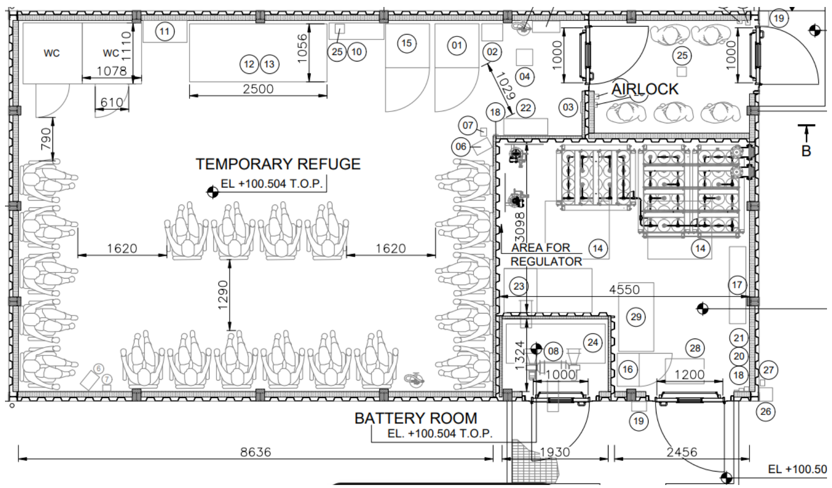
Mega O&G Plant, 8.7 billions USD, including **53 Process Units** and **59 Buildings**, **4 Licensors**, with a peak of around **30.000** workers at site



1 football pitch…
(7,140 m²)

…~**500** football pitches
(3,500,000 m²)

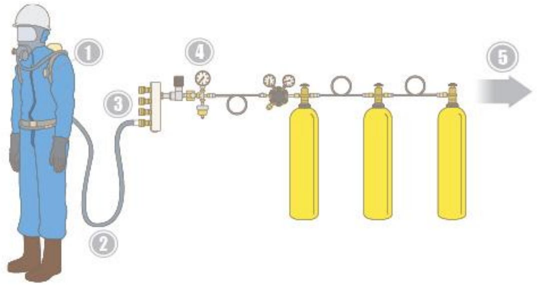
(without considering export pipelines and remote areas)



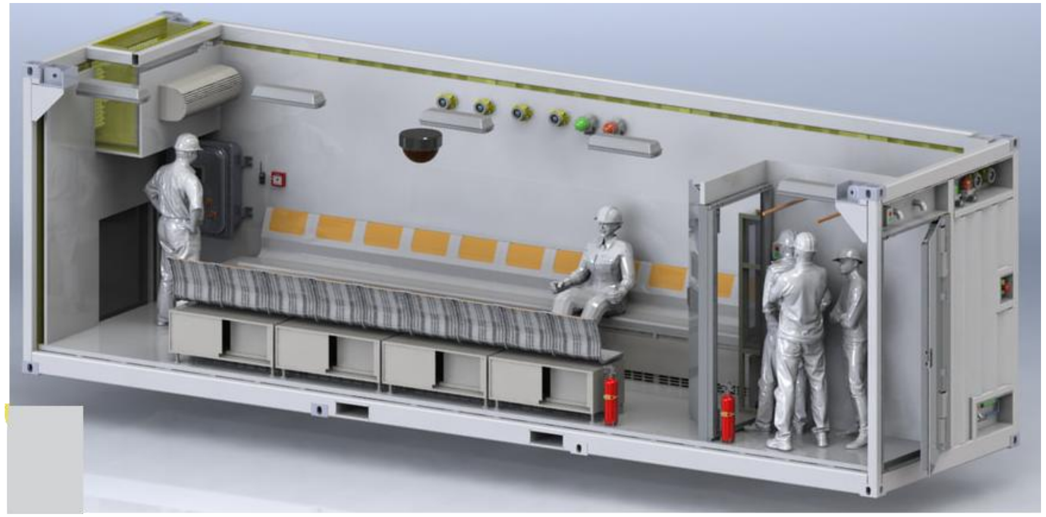
Among several risks:

ultra-sour process

with critical H2S content (up to 35%)



Special safety measures



… AND: <u>CFD modelling</u>

01

Objectives

- ✓ **Providing an overview of CFD modelling**
- ✓ **Touching on CFD application in a complex executive EPC Project**
- ✓ **Sharing useful tips from practical experience**

What this presentation is about…
EPC Contractor's point of view,
turned at Plant Owner

…and what is not:
Specific CFD modelling details
(Consultant's expertise)

02

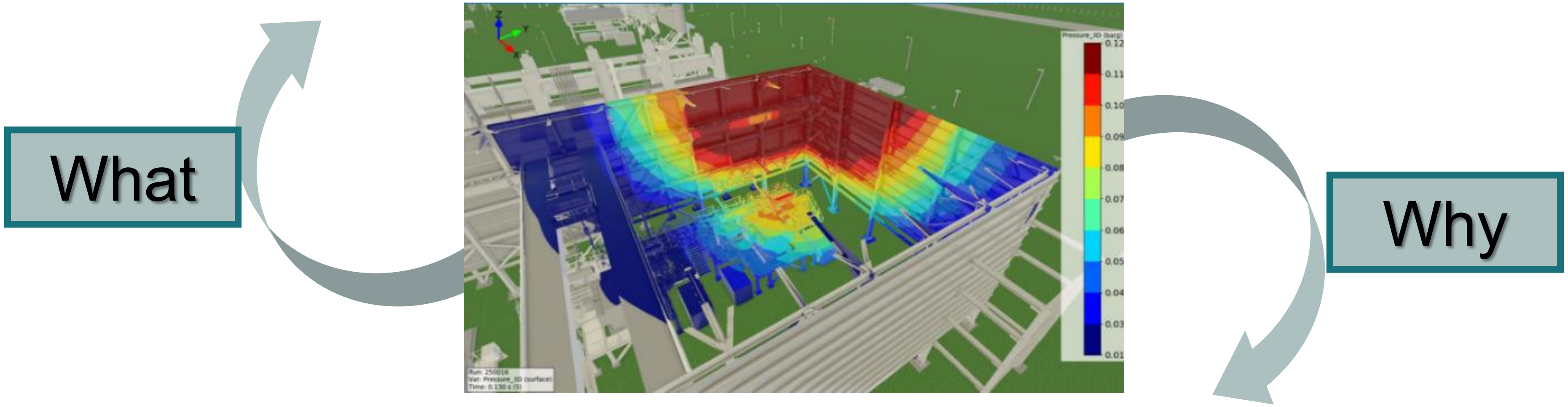
CFD modelling in a nutshell

✓ State-of-the-art in **consequence effects modelling** for ventilation, flammable and toxic gas dispersion, smoke and explosion.

✓ It considers **time dependency** and **volume blockages** causing congestion and turbulence.

✓ **Advanced alternative to integral, empirical or phenomenological 2D models**, giving **more accurate results** (congested areas, complex terrains, low wind, cryogenic and dense gases such as CO_2 or H_2S).

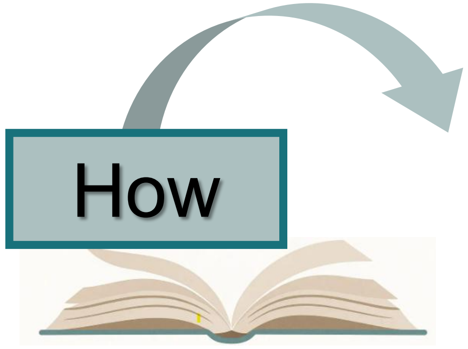
✓ It requires resources in terms of **time and cost**.

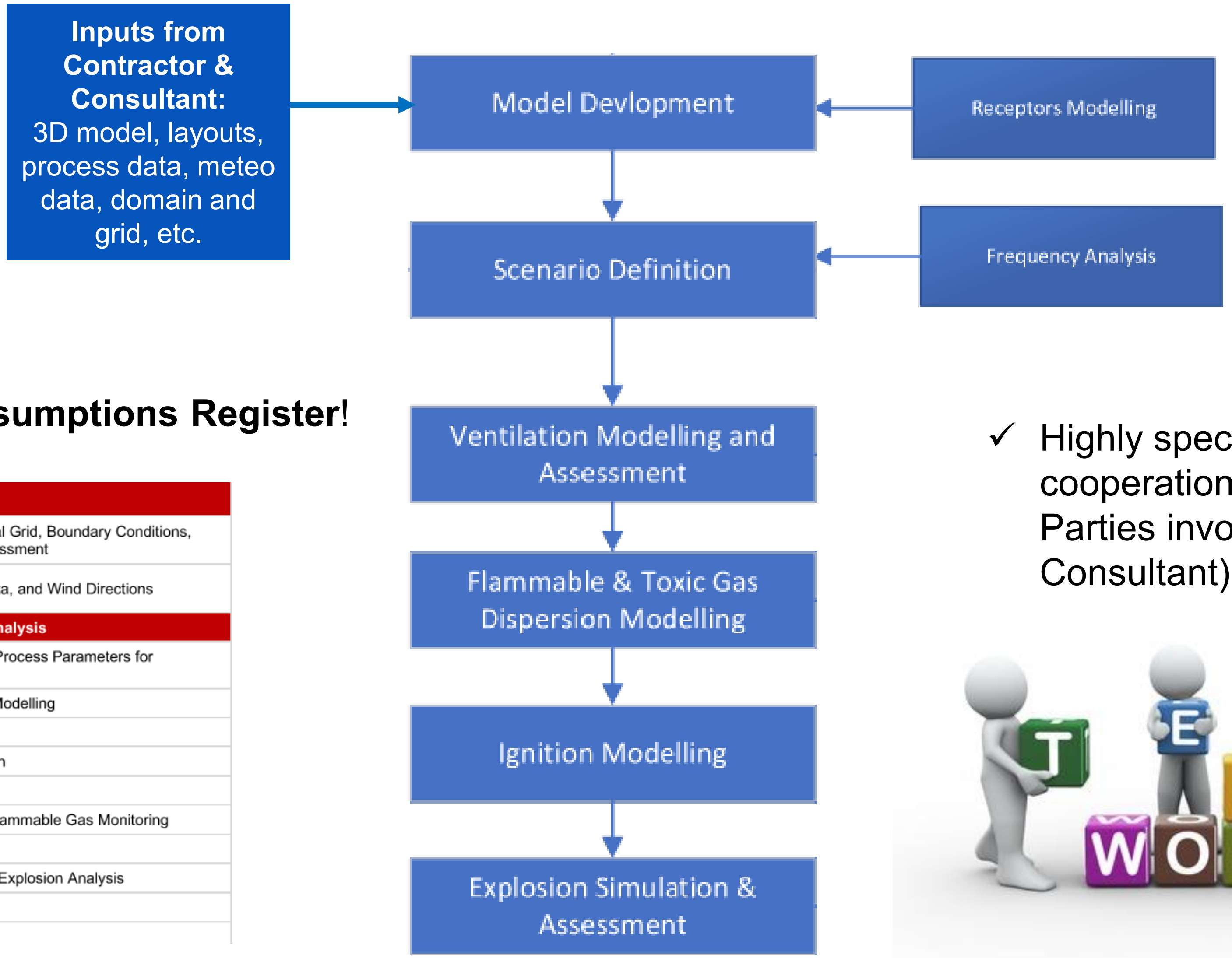


✓ **Validate** the results previously obtained in **FERA/QRA** (done with 2D models), usually **more conservative and less accurate**

✓ **Solve specific design issues** requiring more accurate analysis *(e.g. high H_2S/toxic substances)*

✓ **Obtain benefits** in Plant design (especially in congested areas): layout optimization, saving of materials, facilitation of Operating Procedures in risky areas.





✓ Timely agree the **Assumptions Register**!

6.1 General Assumptions	
01	Software Use, 3D Geometry Model, Numerical Grid, Boundary Conditions, Anticipated Congestions and Ventilation Assessment
02	Environmental Conditions, Meteorological Data, and Wind Directions
6.2 Flammable Dispersion and Explosion Analysis	
03	Release Cases, Locations, Orientations and Process Parameters for Flammable Dispersion Modelling
04	Simulation Matrix for Flammable Dispersion Modelling
05	Receptor List for Explosion Modelling
06	Assessment Criteria for Flammable Dispersion
07	Potential Explosion Sites (PES)
08	Equivalent Stoichiometric Cloud (ESC) and Flammable Gas Monitoring
09	Explosion Modelling
10	Explosion Load Measurement, Receptors for Explosion Analysis
11	Ignition Modelling and Explosion Frequency
12	Explosion Risk Criteria

✓ Highly specialized activity, requiring cooperation and expertise of all Parties involved (Owner, Contractor, Consultant)

Theoretically: the correct detail of structures to ensure modelling accuracy is reached at **90% 3D Model development…**

… practically: EPC Contracts schedules are increasingly squeezed, imposing to procure equipment and materials (particularly Long Lead Items, but not only) in parallel with detailed engineering.

Good compromise: bringing the CFD modelling forward to **60% 3D Model**, providing a correct Anticipated Congestion modelling (ACM) for smaller items (usually up to 4'') not shown yet.

To avoid wrong ACM impacting the results, the Contractor (mastering Plant design) shall guide the Consultant (mastering modelling skills).

03

The application case

The Project

Location: UAE

Plant: Oil&Gas, onshore, receiving feedstock from offshore facilities by pipelines

Products: 1 BSCFD of raw gas, 82.5 MBPD of oil, 76.3 MSTBD of condensate, 9000 TPD of Sulphur and 5030 TPD of NGL, plus 1.52 million tpa of CO_2 captured.

Main process Units: Feedstock Inlet Facilities, Liquid Stabilization, Condensate Hydrotreatment, HPU, Sour Off-gas Compression, AGRU, SRU/TGTU, Booster Compression and Chilling, Dehydration and Mercury Removal, NGL Recovery, Export Compression, ASU, H_2/CO_2 Recovery, Products Export and Pipelines, Product Storages, Utilities.

Among several risks:

- ✓ **ultra-sour process (up to 35% H_2S)**
- ✓ **Flammable and toxic (H_2S, SO_2, CO_2) gas dispersion**
- ✓ **Explosion**

CFD Study required by Contract, cherry-picking specific cases

The CFD Study

Objective 1: Validate the outcomes of Flare Radiation and Vent Dispersion Study

Selected cases: gas dispersion (H2S, LFL in case of flame out, SO2) from HP flare and LP Acid Flare

HP Flare

Parameter	Value	
Flare Stack Tip Height (m) from Ground Elevation	150	
Stack Diameter (inch)	48	
Release Case Description	Case 1 Cooling water failure	Case 2 Confirmed H2S Detection
Mass Flow Rate (kg/h)	1548240	971291
Operating Temperature (°C)	27	17
	Hydrogen - 0.0004 Nitrogen - 0.0032 CO2 - 0.06450 H2S - 0.2108 Methane - 0.6197 Ethane - 0.0460 Propane - 0.0227 i-butane - 0.0052	Hydrogen - 0.0137 Nitrogen - 0.0020 CO2 - 0.1027 H2S - 0.3340 Methane - 0.4803 Ethane - 0.0251 Propane - 0.0200 i-butane - 0.0031

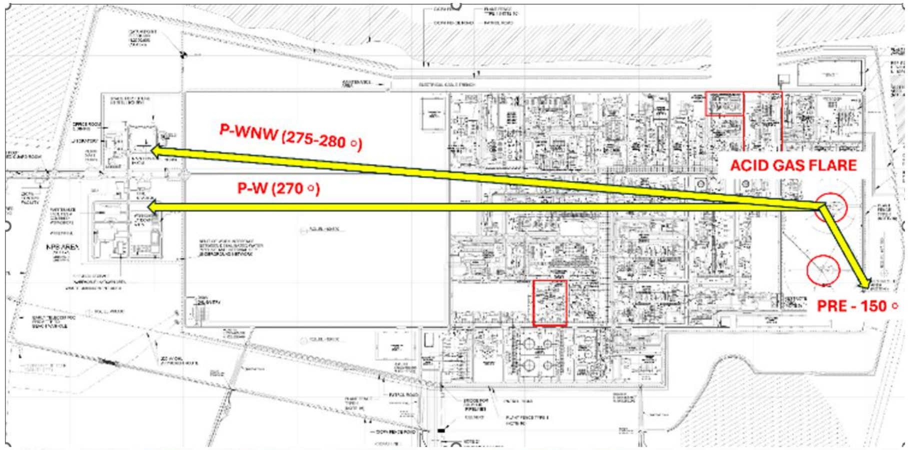
LP Acid Flare

Parameter	Value
Flare Stack Tip Height (m) From Ground Elevation	165
Stack Diameter (inch)	60
Release Case Description	Case 1 + 30% Assist Gas
Mass Flow Rate (kg/h)	739147
Operating Temperature (°C)	40
Composition (% mol)	Hydrogen – 0.0010 Nitrogen – 0.0013 CO2 – 0.1554 H2S – 0.5363 Methane – 0.2256 Ethane – 0.0160 Propane – 0.0053 i-butane - 0

Thresholds considered

Substance	Concentration Level (Threshold)	
	Values	Significance
Toxic Gas (H_2S)	5 ppm	TWA
	10 ppm	STEL
	27 ppm	AEGL 2 – Disabling (Emergency Access Zone -EAZ)
	76 ppm	AEGL 3 – Lethal (Emergency Planning Zone – EPZ)
	100 ppm	IDLH - Yellow Zone limit (25 mm release)
	700 ppm	Amber Zone Limit (25 mm release)
	1000 ppm	Collapse, respiratory paralysis followed by death
Toxic Gas (SO_2)	2 ppm	TLV – TWA
	5 ppm	STEL – TWA
	30 ppm	AEGL 3 – (Emergency Planning Zone -EPZ)
	100 ppm	IDLH
Toxic Gas (CO_2)	5000 ppm	TWA
	30000 ppm	STEL
Flammable Gas	10% LFL, 20% LFL, 50% LFL and 100% LFL	

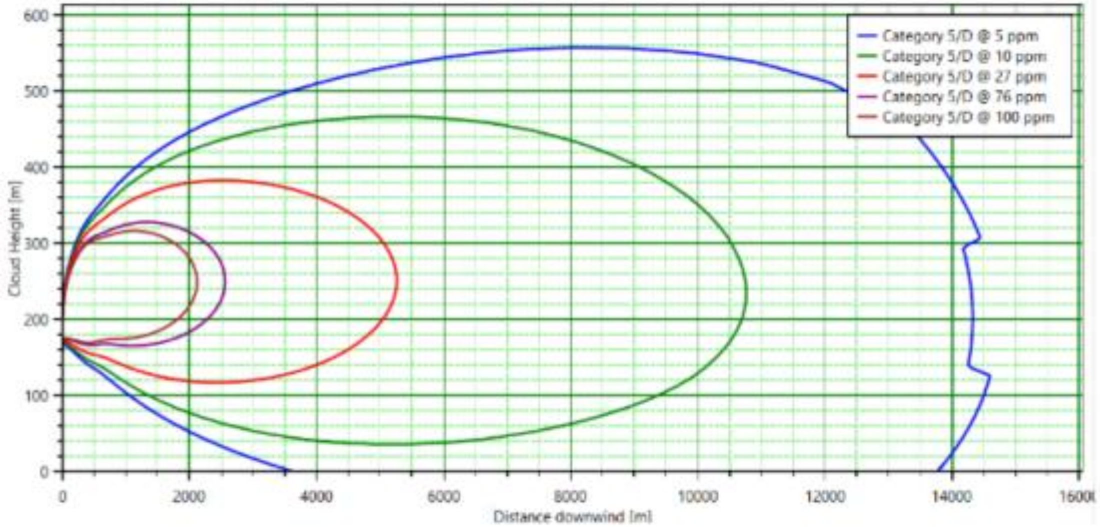
Objective 1: Validate the outcomes of Flare Radiation and Vent Dispersion Study



3 wind directions considered: 2 towards Non Process Buildings, 1 towards prevailing wind
3 conditions considered: wind/atmospheric stability classes 2F, 5D, 10D

Simulation results:

- ✓ The highest concentration of H_2S reaching the sensitive receptors is 46 ppm, with cond. 5D and wind blowing towards SR (wind rose probability: 6%).
- ✓ No threshold concentration is reaching any sensitive receptor, either for SO_2 or LFL



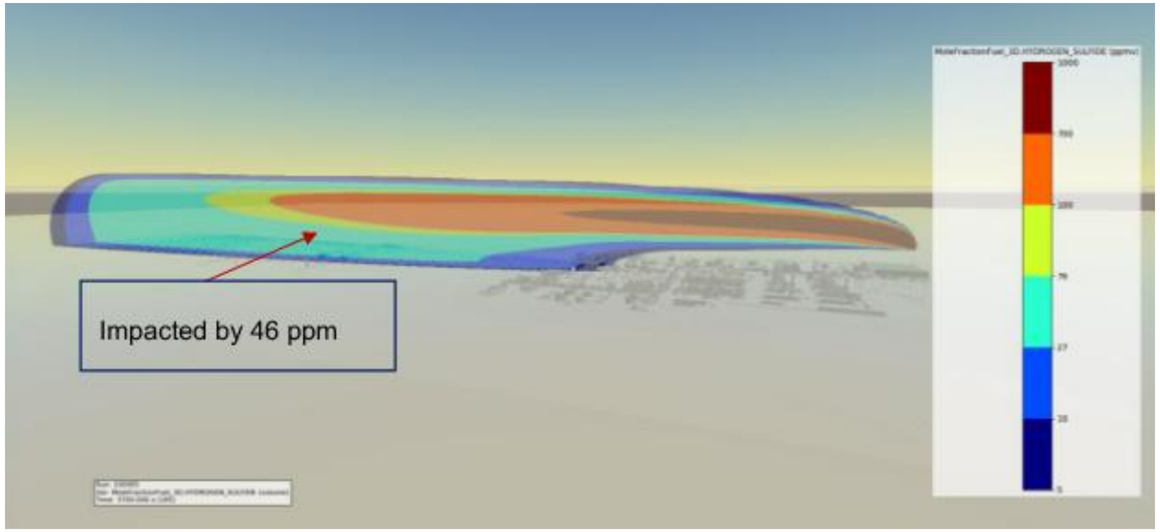


Figure 27 - OPP LP / Acid Gas Flare (Case 1) H2S Dispersion – 5D

Recommendation:

H2S detection and alarm system in place to prevent personnel from extended exposure to H2S and allow the personnel escaping and reaching the designated/unimpaired muster location based on wind direction, in accordance with Emergency Response Plan.

Objective 2: Confirm the design of CO2 vent stacks

Selected cases: dispersion from CO2 Vents at H2/CO2 Recovery Unit and Export Pipeline Block Valve Stations

CO2 Vent at H2/CO2 Recovery Unit

Parameter	Value	
Vent Stack	CO2 Vent	
Vent Stack Tip Height (m)	50	
Vent Diameter (inch)	24	
Release Case Description	Actual Cryogenic	Guaranteed Contaminants
Mass Flow Rate (kg/h)	175203 x 1.1	174020 x 1.1
Operating Temperature (ºC)	30.5/-30.5	30.5/-30.5
Composition (% mol)	Hydrogen – 0.0053 Nitrogen – 0.0029 CO2 – 0.9828 Argon – 0.0081	Hydrogen – 0.0100 Nitrogen – 0.0200 CO2 – 0.9550 H2S – 0.0004 H2O – 0.0004 Argon – 0.0100 CO – 0.0020 COS – 0.0002 CS2 – 0.0016 M-Mercaptan – 0.0002

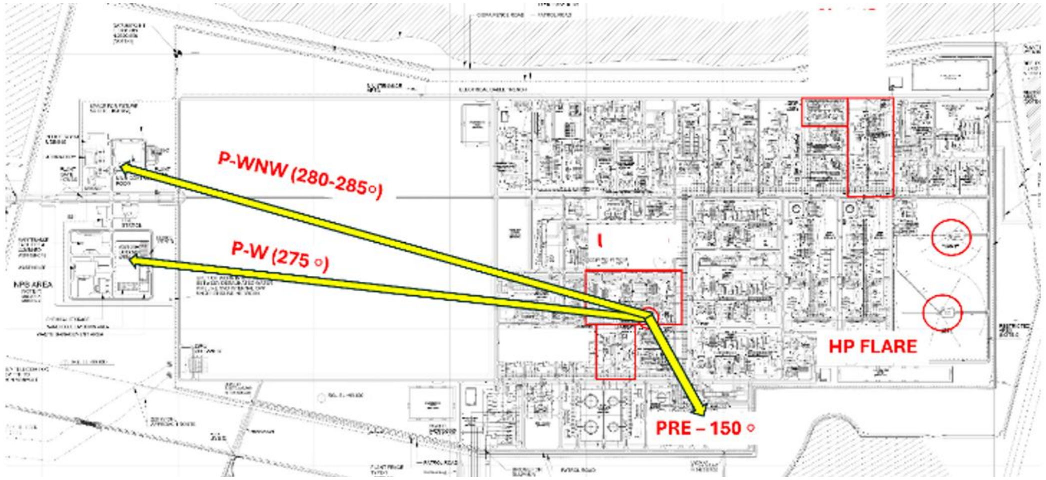
CO2 Vent at Export Pipeline BVS

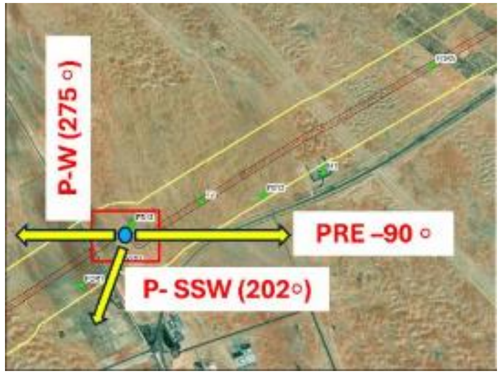
Parameter	Value	
Vent Stack	CO2 Vent	
Vent Stack Tip Height (m)	25	
Vent Diameter (inch)	12	
Release Case Description	Actual Cryogenic	Guaranteed Contaminants
Mass Flow Rate (kg/h)	222719	222719
Operating Temperature (ºC)	-75.9	-75.9
Composition (% mol)	Hydrogen – 0.0053 Nitrogen – 0.0029 CO2 – 0.9828 Argon – 0.0081	Hydrogen – 0.0100 Nitrogen – 0.0200 CO2 – 0.9550 H2S – 0.0004 H2O – 0.0004 Argon – 0.0100 CO – 0.0020 COS – 0.0002 CS2 – 0.0016 M-Mercaptan – 0.0002

Thresholds considered

Toxic Gas (CO_2)	5000 ppm	TWA
	30000 ppm	STEL

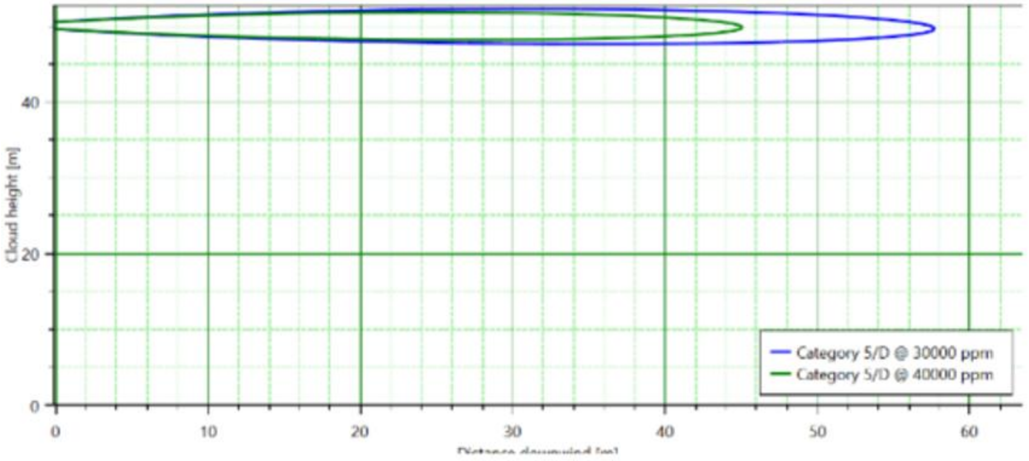
Objective 2: Confirm the design of CO2 vent stacks



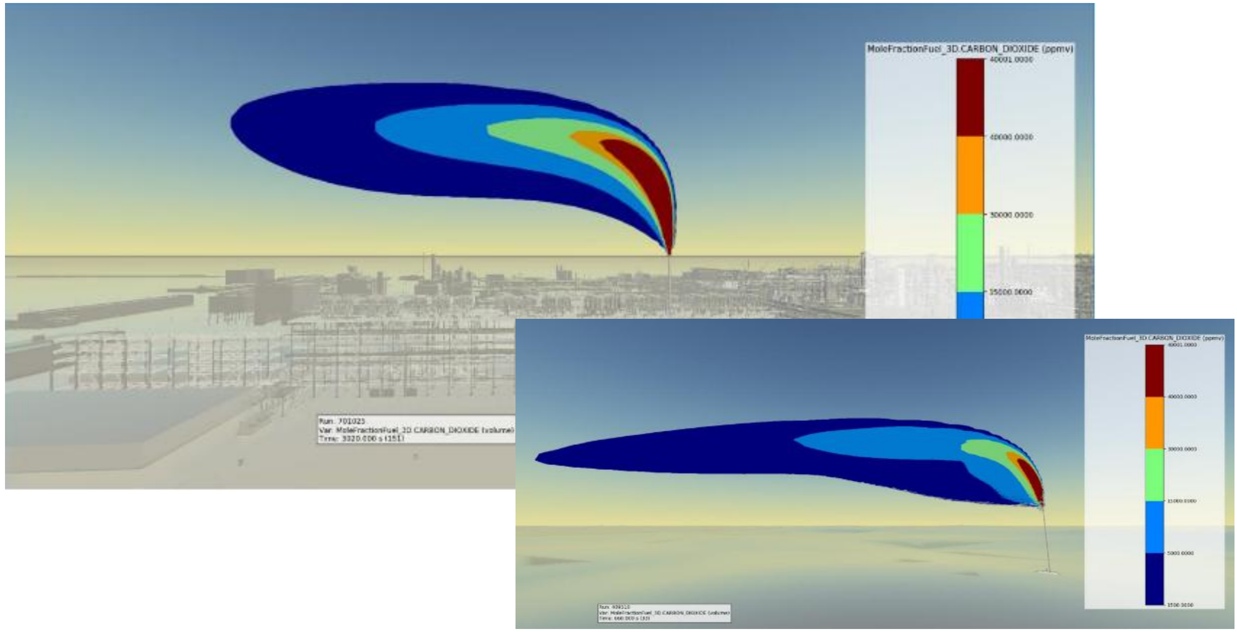


3 wind directions considered:
2 towards Non Process Buildings, 1 towards prevailing wind
3 wind conditions considered:
atmospheric stability classes 2F, 5D, 10D

Simulation results: ✓ No sensitive receptor is affected by monitored concentration levels under all wind directions and wind conditions



CO2 Vent (Case 1) – CO2 Gas Dispersion – 5D



Recommendations: *None*

Objective 3: Validate the outcomes of FERA / QRA

- ✓ **volume/extension of flammable gas cloud**
- ✓ **probabilistic blast load (overpressures and durations) following delayed ignition of flammable gas clouds at targets of interest (i.e. all buildings, critical HSECES and EER facilities)**

Selected cases: flammable gas dispersion and explosion in 3 Units (Condensate Hydrotreatment, HPU, NGL Recovery)

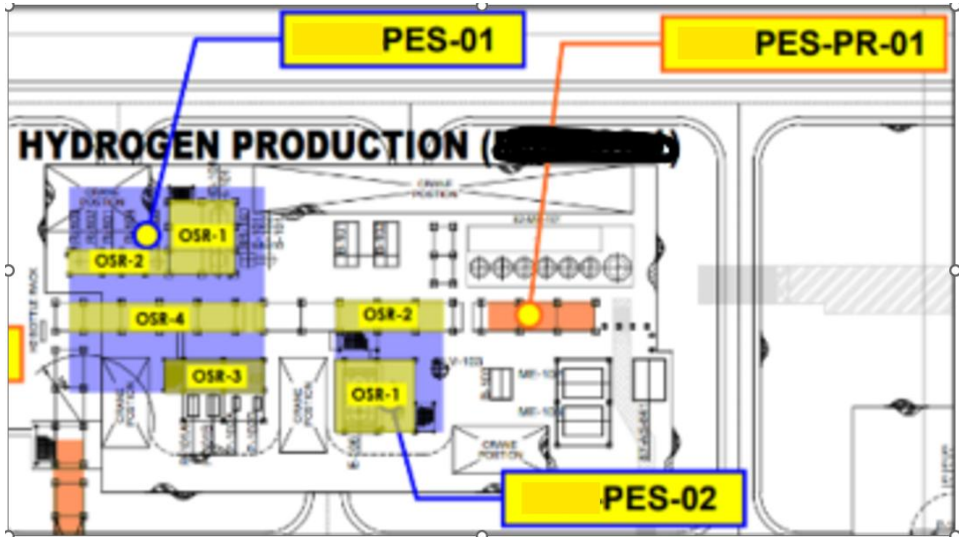
Model development: 60% 3DM + Anticipated Congestion Modelling of small bore piping not shown yet

→ In first draft, wrong assigment of ACM! Contractor's guidance to correctly place the missing solids

According to Assumptions Register:
- ✓ 4 release sizes (5mm, 10mm, 100mm, 150mm)
- ✓ 3 gas release directions
- ✓ 3 atm wind/stability conditions (2F, 5D & 10D)
- ✓ 3 wind directions for each release scenario, towards congested areas or PES that may impact the dispersion analysis.

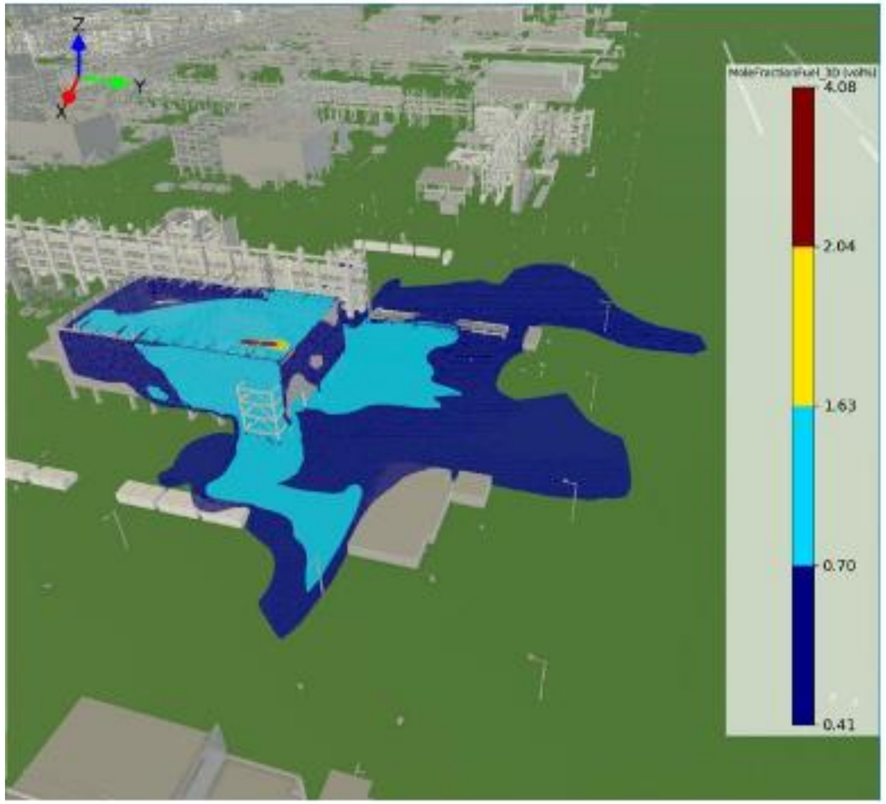
→ Joint review of PES with Owner, Contractor and Consultant, before running the simulation

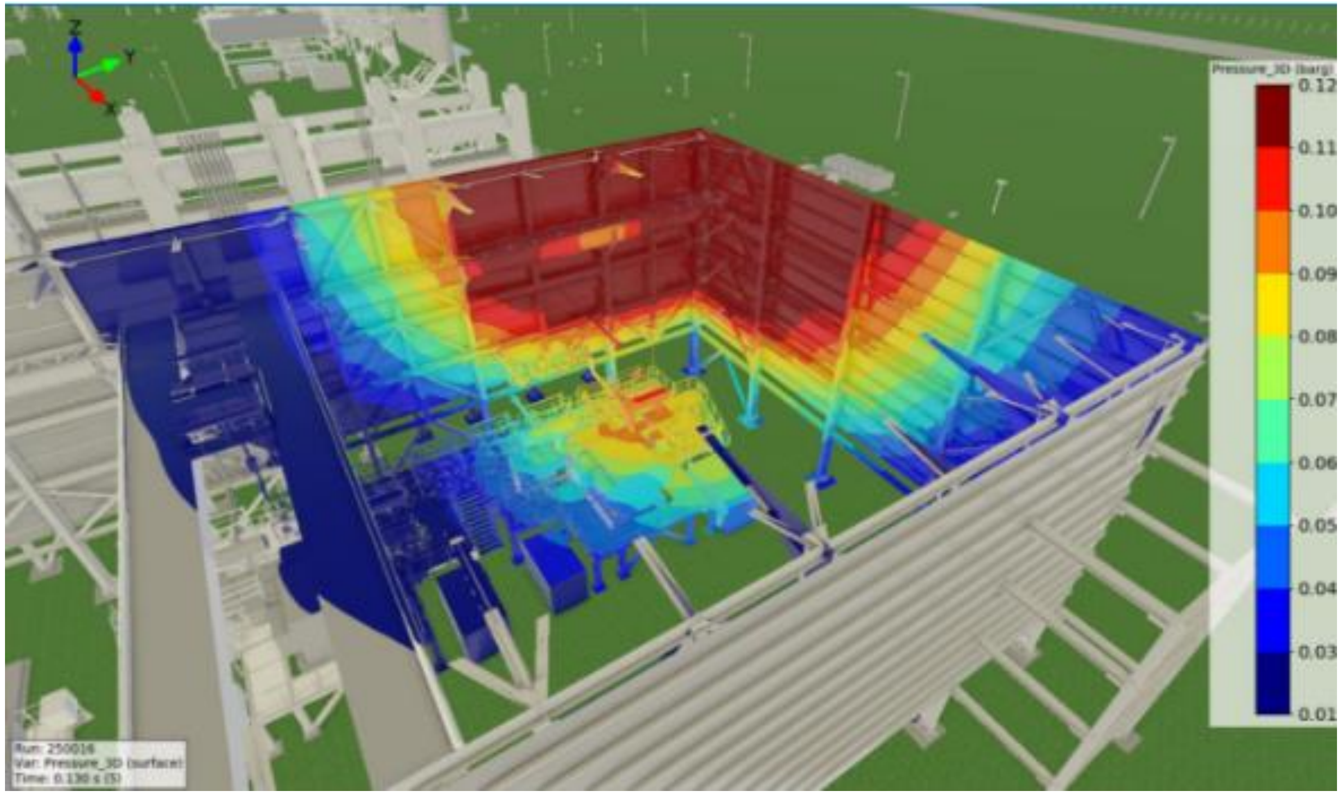
Definition of Potential Explosion Sites (PES): congested areas where flammable gas cloud can accumulate leading to potential explosion



Objective 3: Validate the outcomes of FERA / QRA

Simulation results for identified receptors: The calculated overpressure loads (reflected, peak side-on and dynamic) are lower compared to the FERA results.





PES Hydrotreatment Unit Make-up Gas Compressors Shelter: Flammable dispersion Contour plot of 10%, 15%, 40%, 50%, 100% LFL with the leak size of 25 mm, leak direction +Y, wind condition – 2m/s & F and wind direction – 90 degrees

PES Hydrotreatment Unit Make-up Gas Compressors Shelter: Overpressure Surface Plot of flammable cloud 230.64 m3 (class 1) with Ignition at the Centre

04

The study outcomes

The Study outcomes

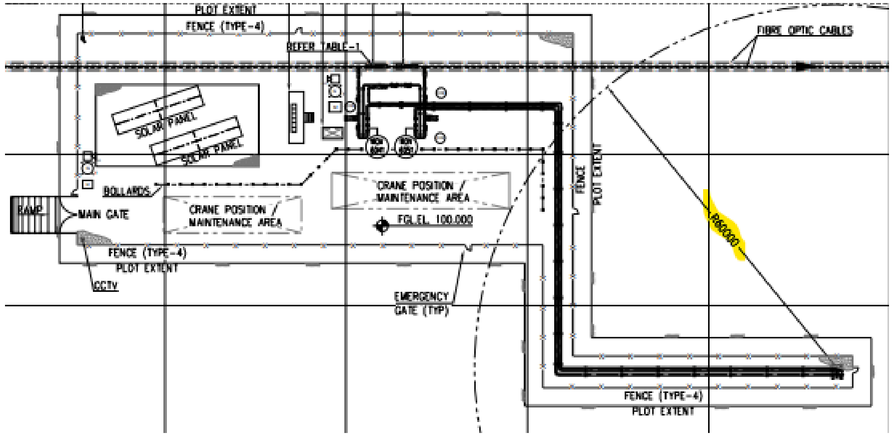
- ✓ **Toxic and flammable gas dispersion from HP/LP Flares in case of flame-out:**

CFD more accurate results compared to FERA (46 ppm H_2S in worst case, instead of 10 ppm), in any case still tolerable.
Confirmation of mitigation measures and Emergency Response Plan, avoiding impacts on design and Project schedule.

- ✓ **CO_2 dispersion from CO_2 vents at H_2/CO_2 Recovery Unit and Export Pipelines BVS:**

CFD Study results confirmed the values calculated in FERA.

Previous layout was conservative, considering 60 m safety distance and an “S”-shape of pipeline creating clashes with existing facilities, issues to pipelines corridor.
CFD results confirmed the feasibility of a distance reduction to 15 m (minimum layout distance stated in Project Standards).



- ✓ **FERA validation:** CFD results might have allowed the Project to decrease the DALs considered in FERA for the blast design of buildings. However, the Owner decided to keep a conservative approach and consider FERA DALs.

E.g. Electrical SS close to Condensate Hydrotreatment Unit:

FERA/BRA:		**CFD:**
VCE side-on overpressure > 0.1 bar with explosion DAL for 1E-04/y	**VS**	VCE side-on overpressure > 0.012 bar with explosion DAL for 1E-04/y

05

Conclusions

Takeaway tips

CFD modelling is recommended to evaluate more accurately **specific cases**: congested areas, complex terrains, highly toxic releases, dispersion of cryogenic and dense fluids. CFD is time-consuming, **cherry picking is required!**

Advantages of CFD modelling: confirm suitability of safety measures in place, layout optimization, saving of materials, facilitation of Operating Procedures in risky areas.

Teamwork requiring all involved Parties to cooperate, merge expertise, timely share/agree the assumptions.

Considering Projects tight schedules and CFD complexity, **check the activity planning**! Possibility to bring forward to 60% 3D model through a correct modelling of Anticipated Congestion.

Thank you for your attention

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