WHEN TRUST MATTERS

Managing the Major Accident Potential of Carbon Capture and Storage CO_2

IChemE Hazards 31 Conference

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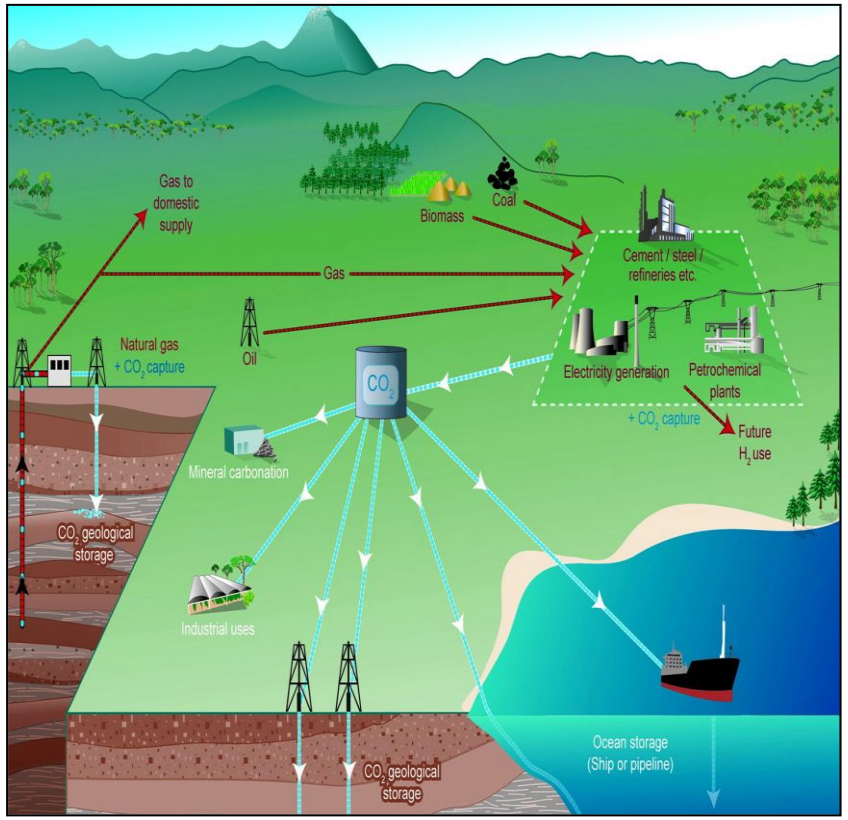
The implementation of Carbon Capture and Storage (CCS) will introduce the need to handle very large inventories of impure carbon dioxide (CO_2) and this will introduce the potential for major accident events.

The purpose of today's presentation is to raise awareness of some of the properties and behaviours of CCS CO_2 and highlight how they could cause or contribute to a major accident event.

CCS CO_2 Context and Challenges

- Very large inventories of CO_2 located across land and subsea with some located near populated areas
- Different stakeholders and operators along the CCS chain with hazard management dependency between them
- Impurities vary considerably between sources and they can change the properties and behaviour of CO_2 stream significantly
- Powerful drivers for rapid, cost efficient and widescale deployment

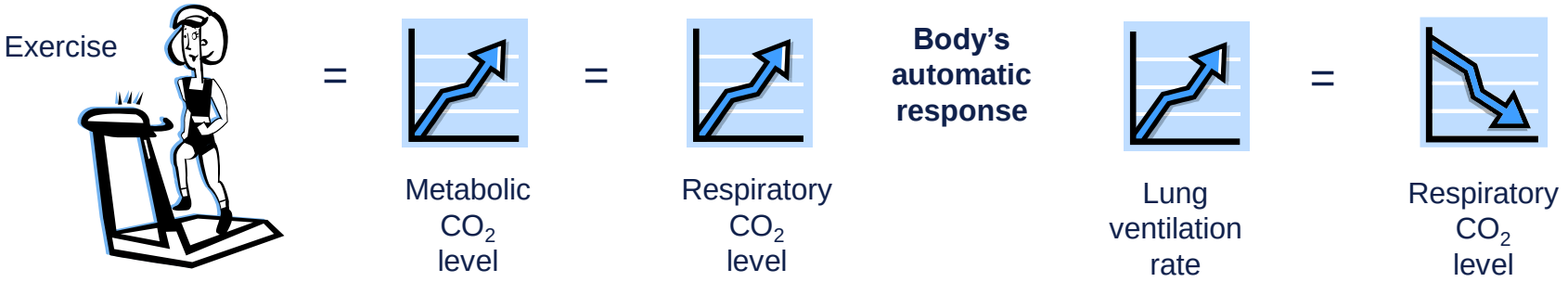


Carbon Dioxide - Refresher

- At atmospheric conditions CO_2 can only exist as a vapour
- CO_2 vapour is heavier than air
- CO_2 vapour is colourless, odourless & invisible
- Dissolved in water CO_2 forms carbonic acid
- CO_2 can exist in one of four phases: vapour/gas, liquid, solid and supercritical
- “Dense phase” CO_2 is not a real phase – it’s a collective term for liquid and supercritical CO_2
- Solid CO_2 is known as ‘dry ice’ which has a surface temperature of -78˚C at 1 atm.
- Supercritical CO_2 has viscosity similar to gas but density closer to a liquid
- Liquid and particularly supercritical CO_2 is an excellent solvent
- CO_2 poses an asphyxiation hazard …

… but CO_2 also poses a greater toxic hazard

- Humans are sensitive to changes in CO_2 concentrations in their respiratory system
- CO_2 levels control the rate and depth of breathing (i.e. it is a powerful breathing stimuli)



- Inhaling elevated concentration of CO_2 triggers body's automatic response

CO_2 % in Air	Exposure Time	Effect on Humans
3%	1 hour	Mild headache, sweating, difficult breathing
10%	< 5 mins	Dizziness, sweating, rapid breathing, unconsciousness
17%	< 2 mins	Unconsciousness, convulsions, coma, death

- CO_2 when inhaled above around 5% in air is a hazard and >17% is immediately life-threatening
- CO_2 is a toxic substance and an asphyxiant but toxic effects occur at significantly lower CO_2 concentrations

Causes Of Loss Of Containment

- Internal corrosion due to presence of water
- Component failure due to inappropriate materials
- Low temperature embrittlement of containment envelope
- Overpressure from density change in trapped inventory
- Overpressure from phase change in trapped inventory

- Common causes (e.g. 3rd party mechanical impact, etc.)

- Lack of relevant CO_2 awareness and/or competence

Photo courtesy of DNV Spadeadam

Potential Escalation

- Propagating crack
- Leak enlargement from low temperature embrittlement
- Adjacent failures from low temperature embrittlement
- CO_2 Boiling Liquid Evaporating Vapour Explosion (BLEVE)
- Build-up of toxic substances at location of release
- Road traffic accident due to lack of visibility
- Engulfment of ships alongside an offshore platform

- Lack of relevant CO_2 awareness and/or competence

Photo courtesy of the DNV CO2PIPETRANS JIP

Potential Consequences

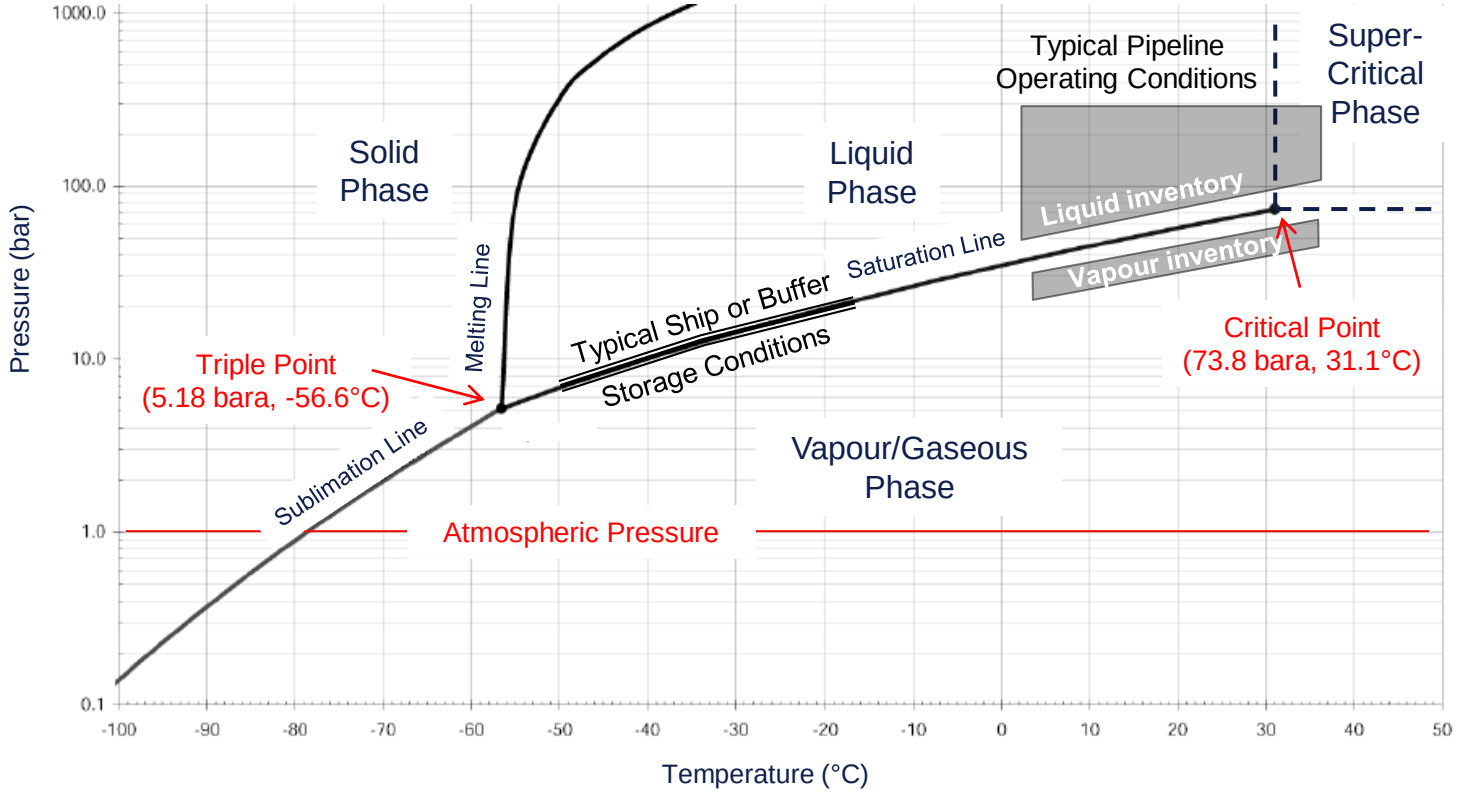
- Inhalation of elevated CO_2 concentrations in air
- Inhalation of, or exposure to, very cold air mixture
- Contact with solid CO_2 or cooled surfaces
- Rapid expansion energy
- Projectiles
- Lack of visibility

- Lack of relevant CO_2 awareness and/or competence

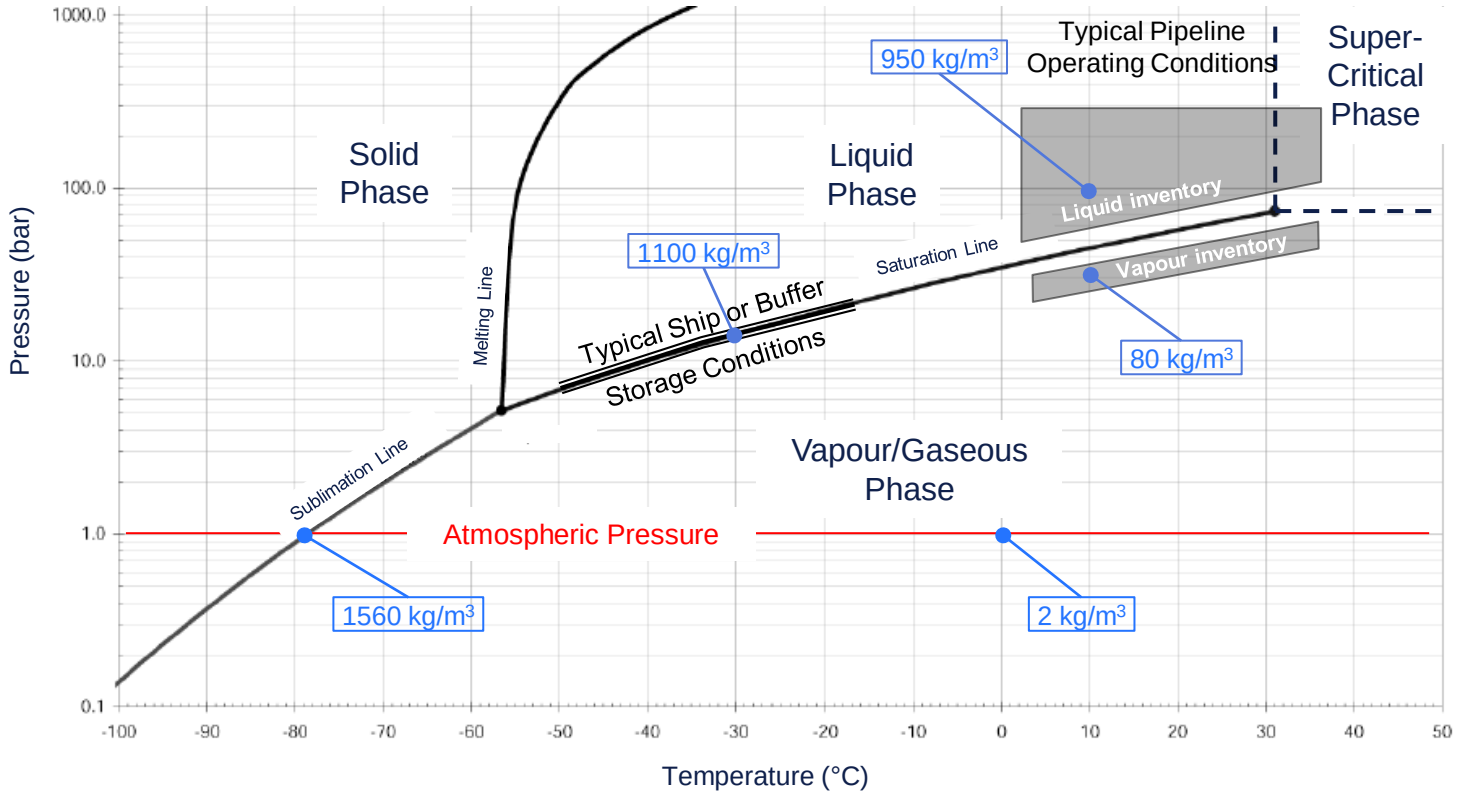
[8” Pipeline Rupture, Google “Spadeadam CO2”]

Photo courtesy of DNV Spadeadam

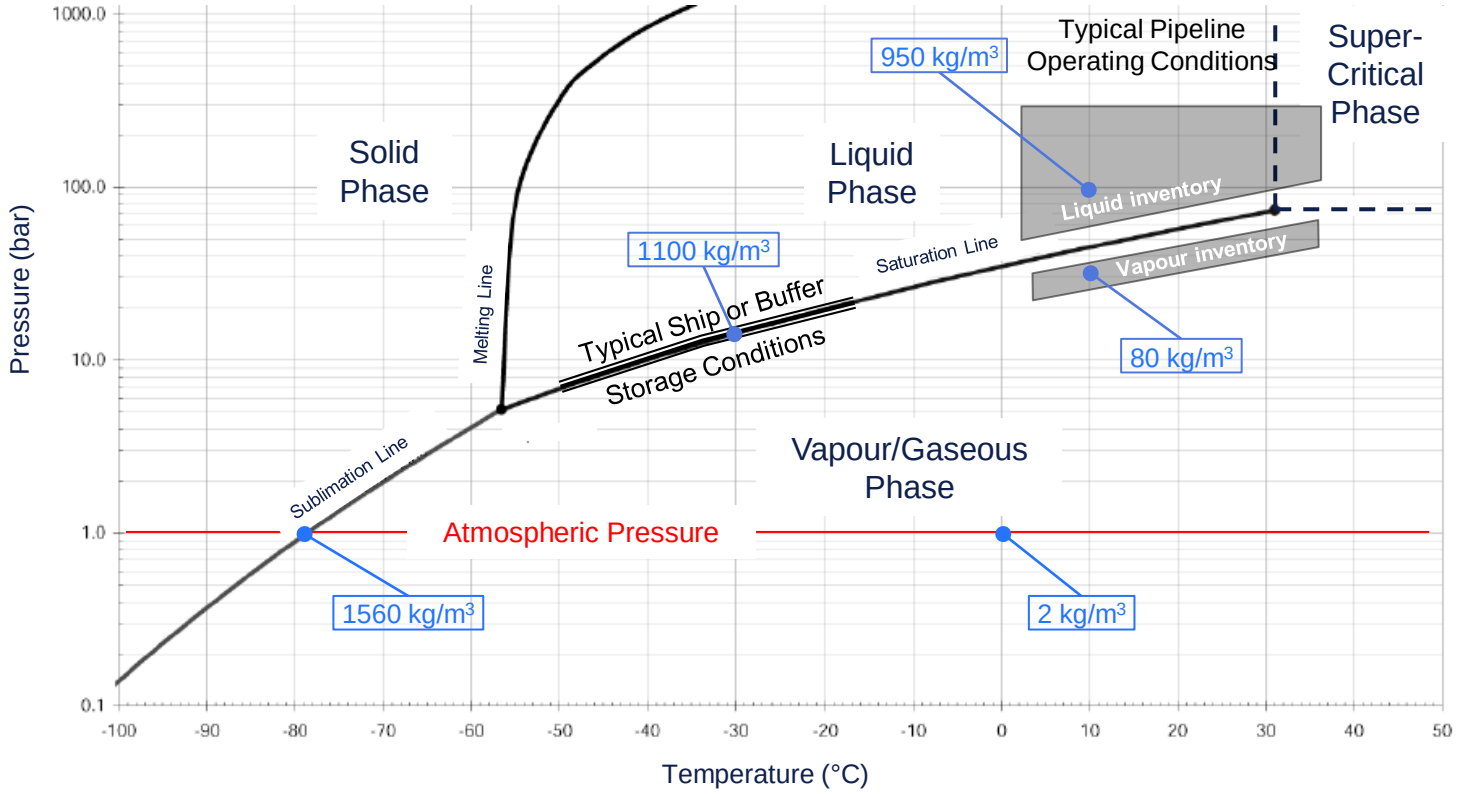
Pure CO_2 Phase Diagram with CCS Information



Pure CO_2 Phase Diagram with CCS Information



Pure CO_2 Phase Diagram with CCS Information



Example inventories:

100km 90cm dia. gas pipeline:

≈ **5,000 tonnes CO_2**

≈ 2.5x10^6 m^3 of CO_2 vapour at 1 atm, 0°C

100km 90cm dia. liquid pipeline:

≈ **60,000 tonnes CO_2**

≈ 30x10^6 m^3 of CO_2 vapour at 1 atm, 0°C

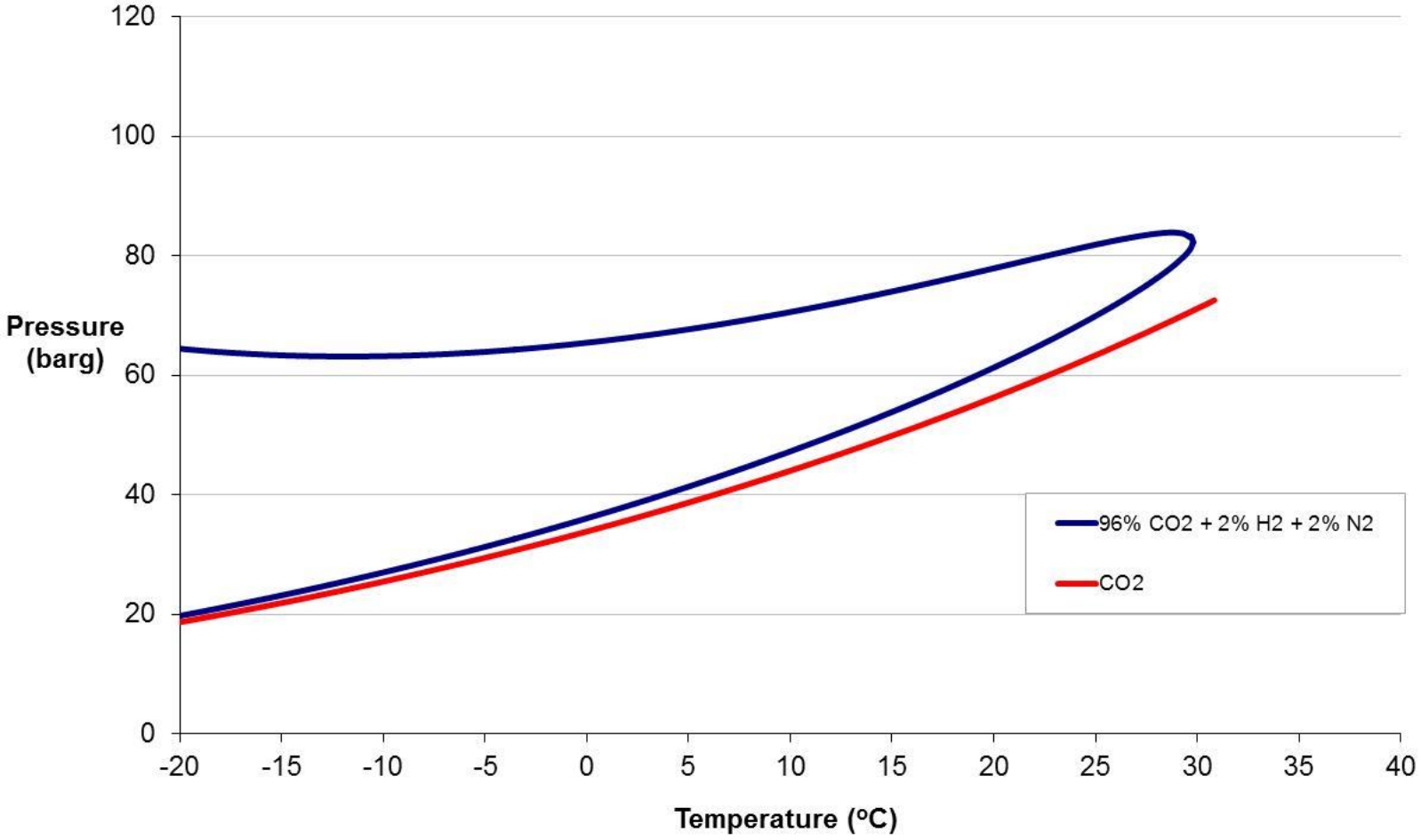
10m high 20m dia. 2-phase storage tank:

≈ **3,500 tonnes CO_2**

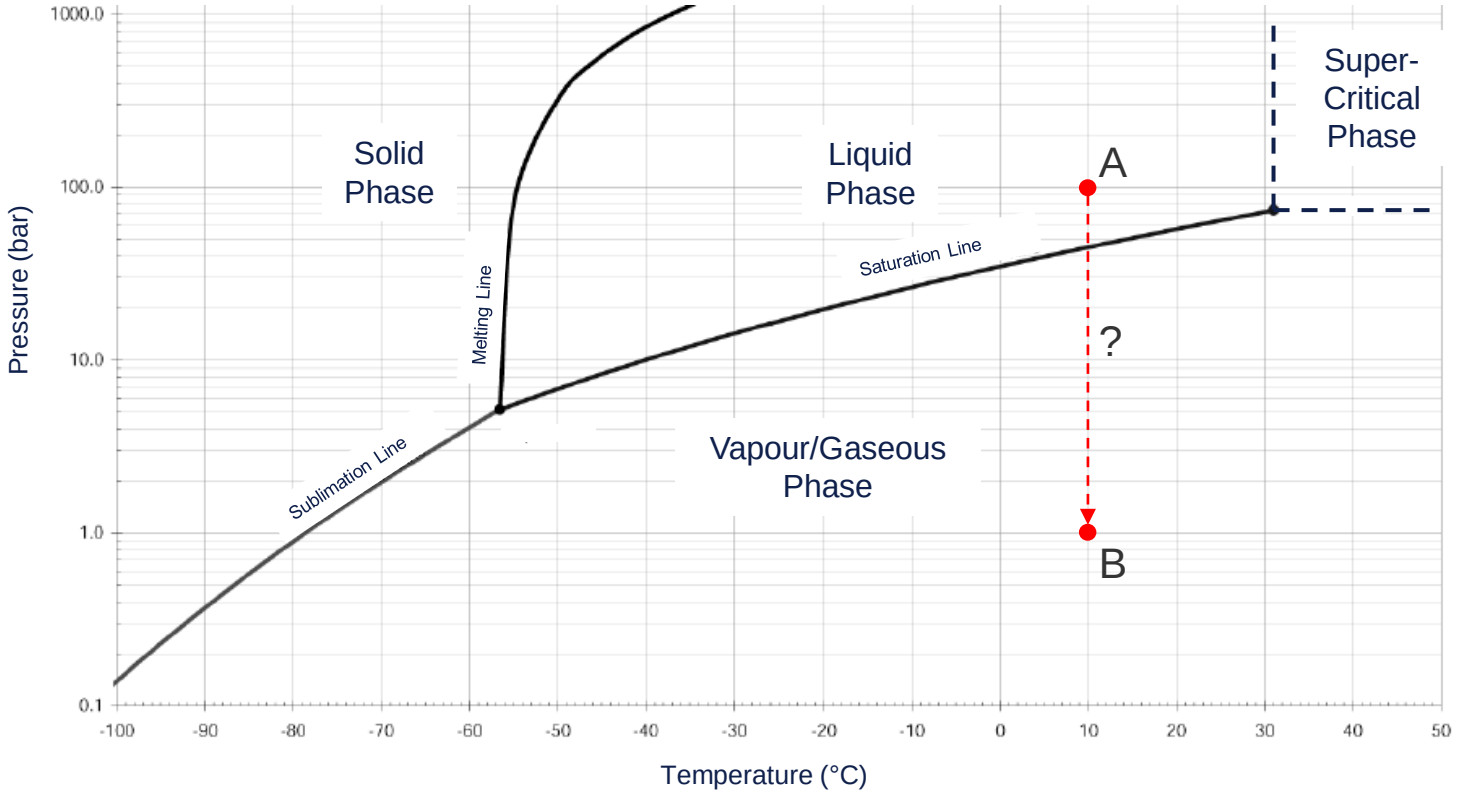
≈ 1.8x10^6 m^3 of CO_2 vapour at 1 atm, 0°C

- At atmospheric conditions CO_2 can only exist as a vapour
- CO_2 vapour is a heavier than air
- CO_2 when inhaled above around 5% in air is a hazard

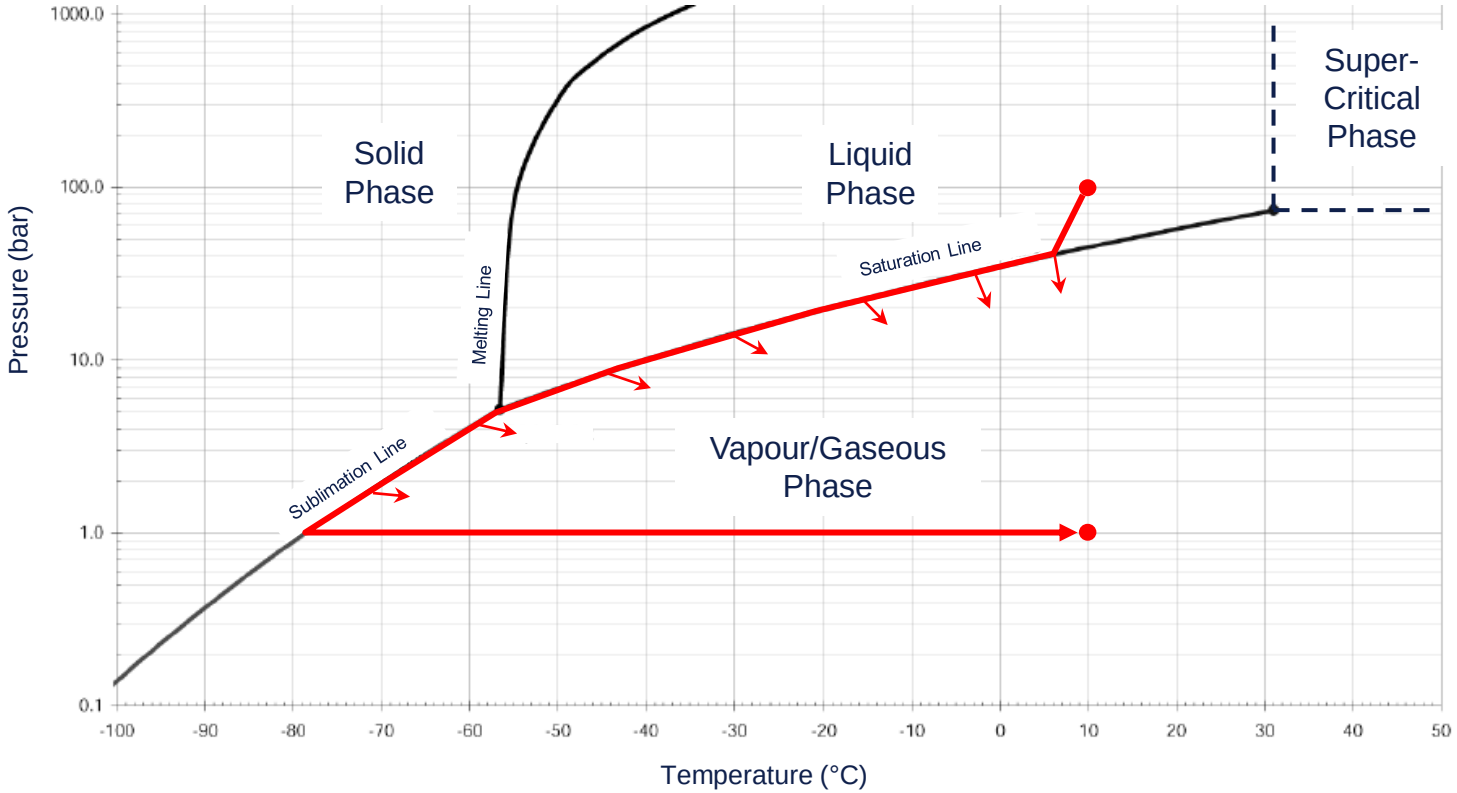
Effect of Impurities On Saturation Line

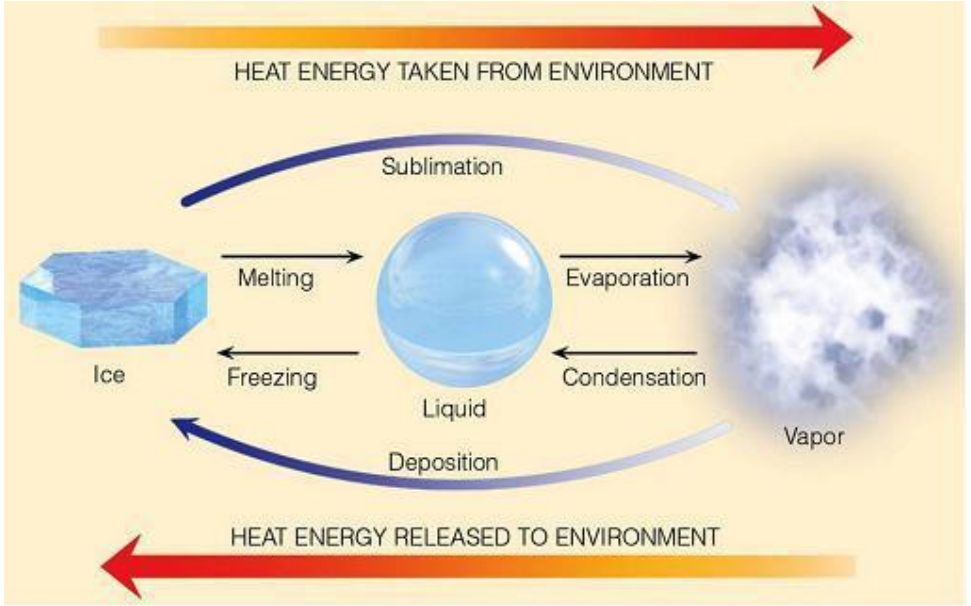


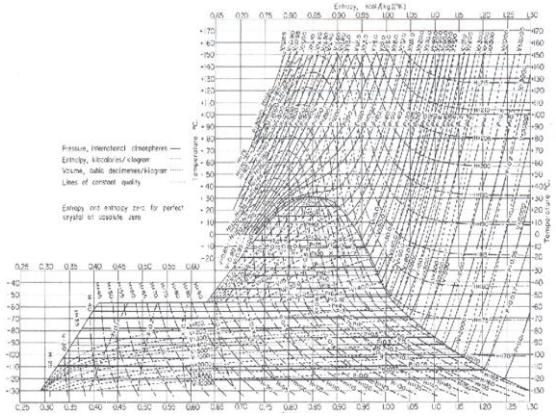
Depressurising Liquid Phase CO_2



Depressurising Liquid Phase CO_2

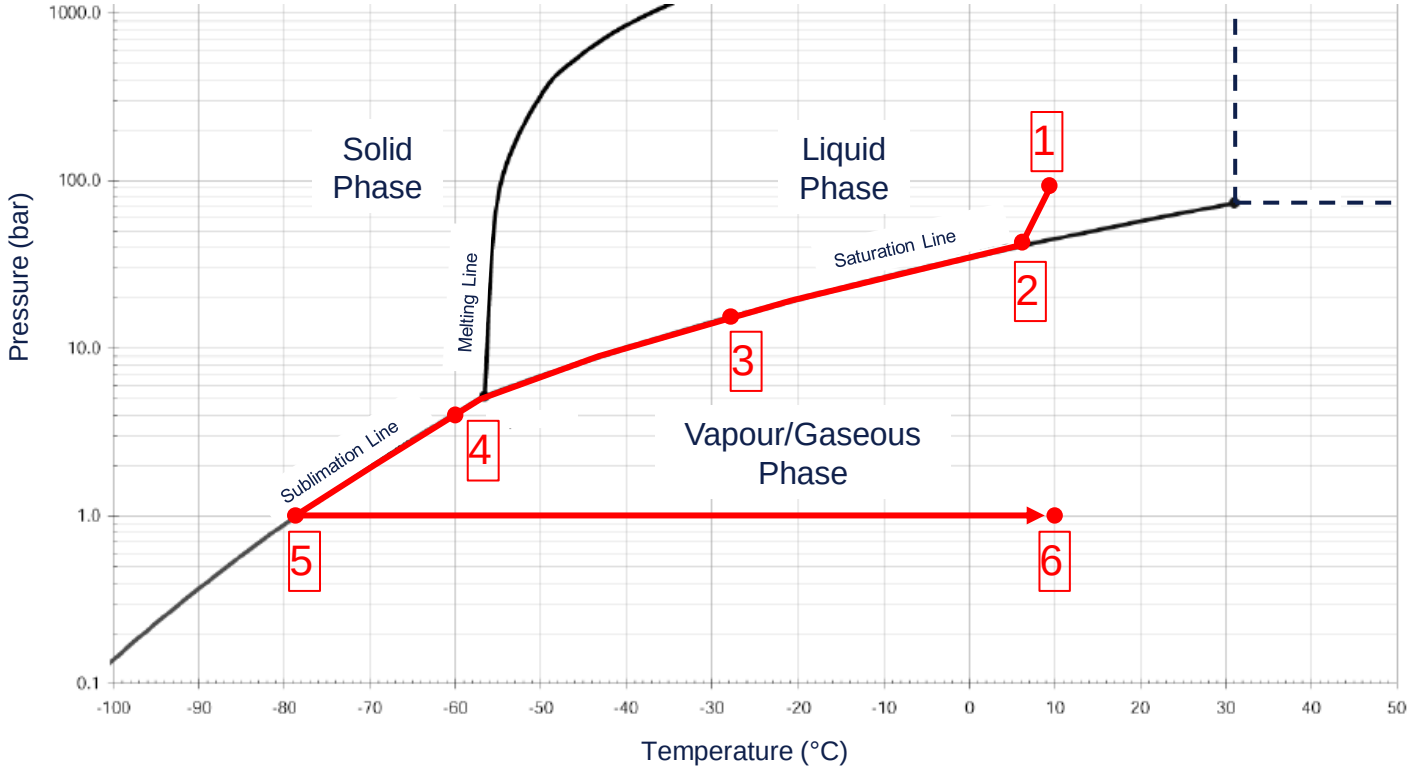






Temperature – Entropy diagram

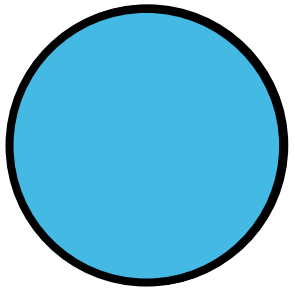
Inventory Journey



[1]

100 bar

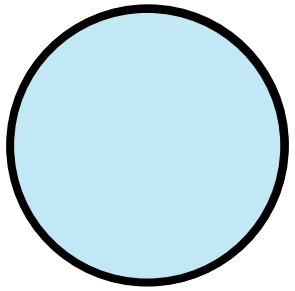
10°C



[2]

40 bar

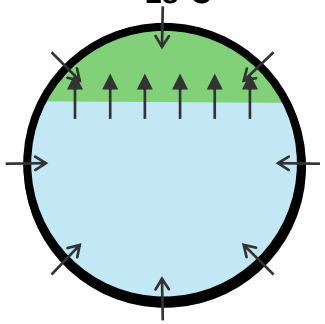
7°C



[3]

15 bar

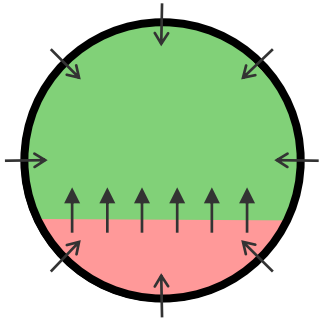
-28°C



[4]

4 bar

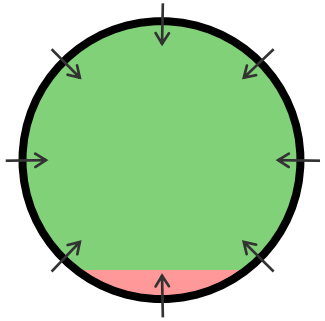
-60°C



[5]

1 bar

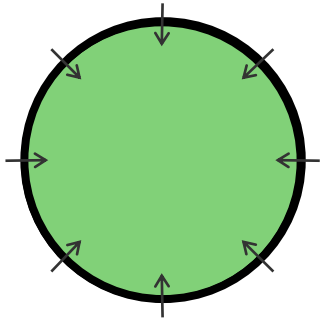
-78°C



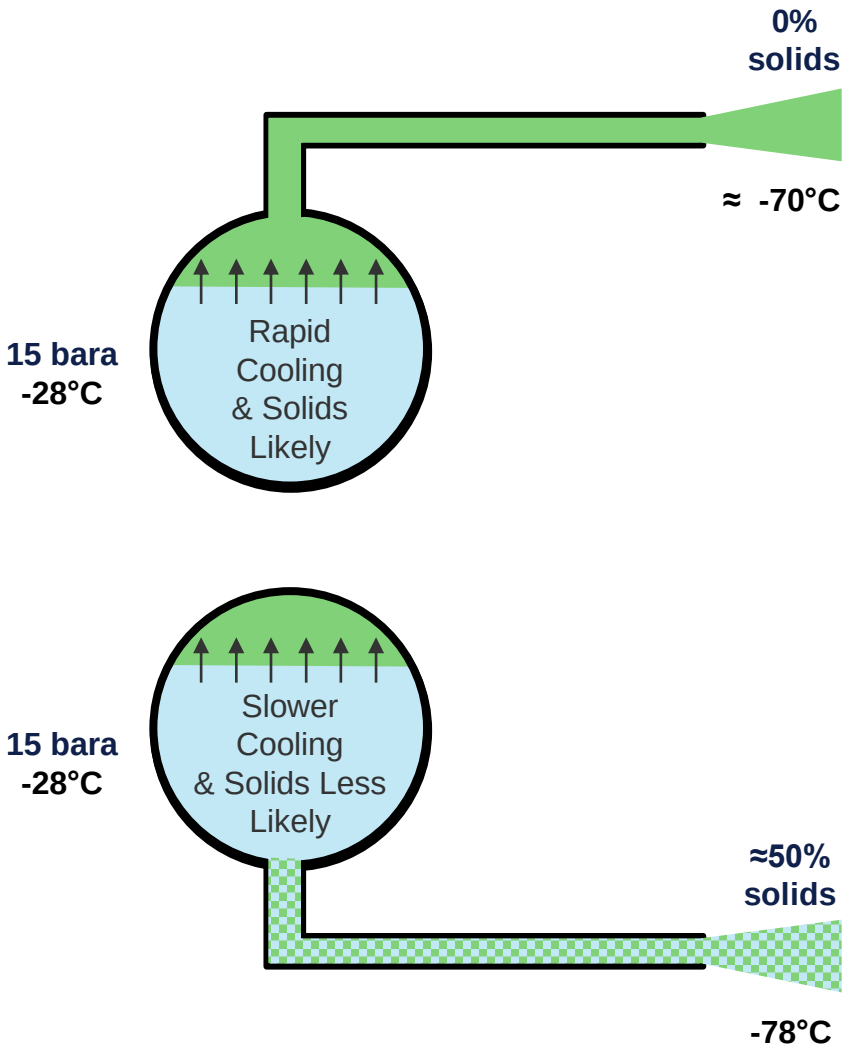
[6]

1 bar

10°C



System Venting or Leak



150 Bar ½” Liquid 5°C ‘Cold’ CO_2 Release

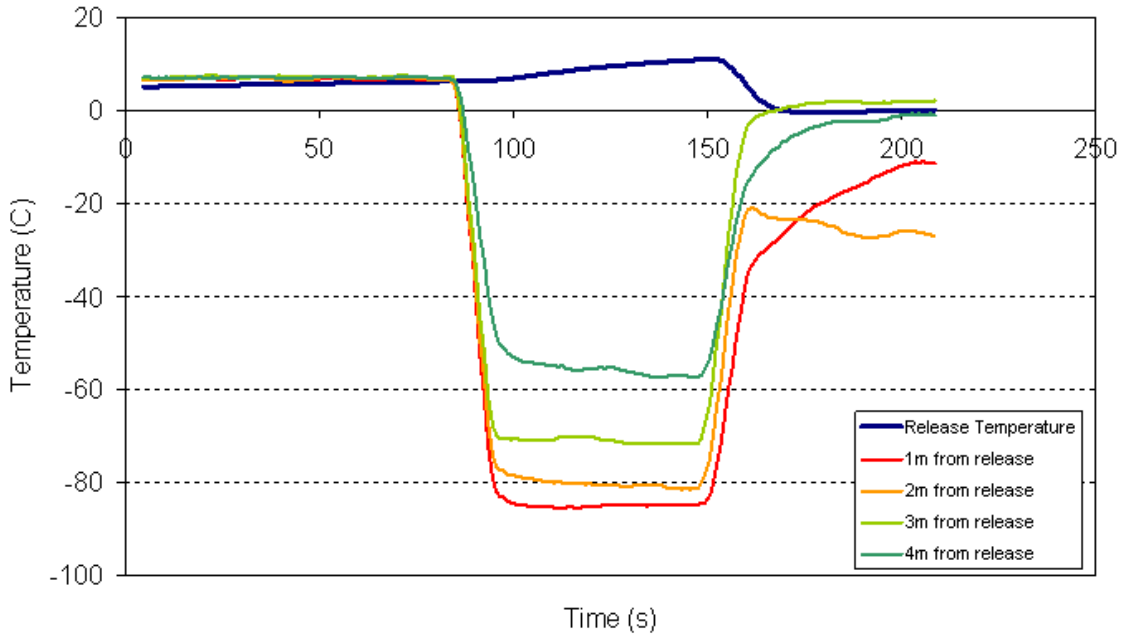
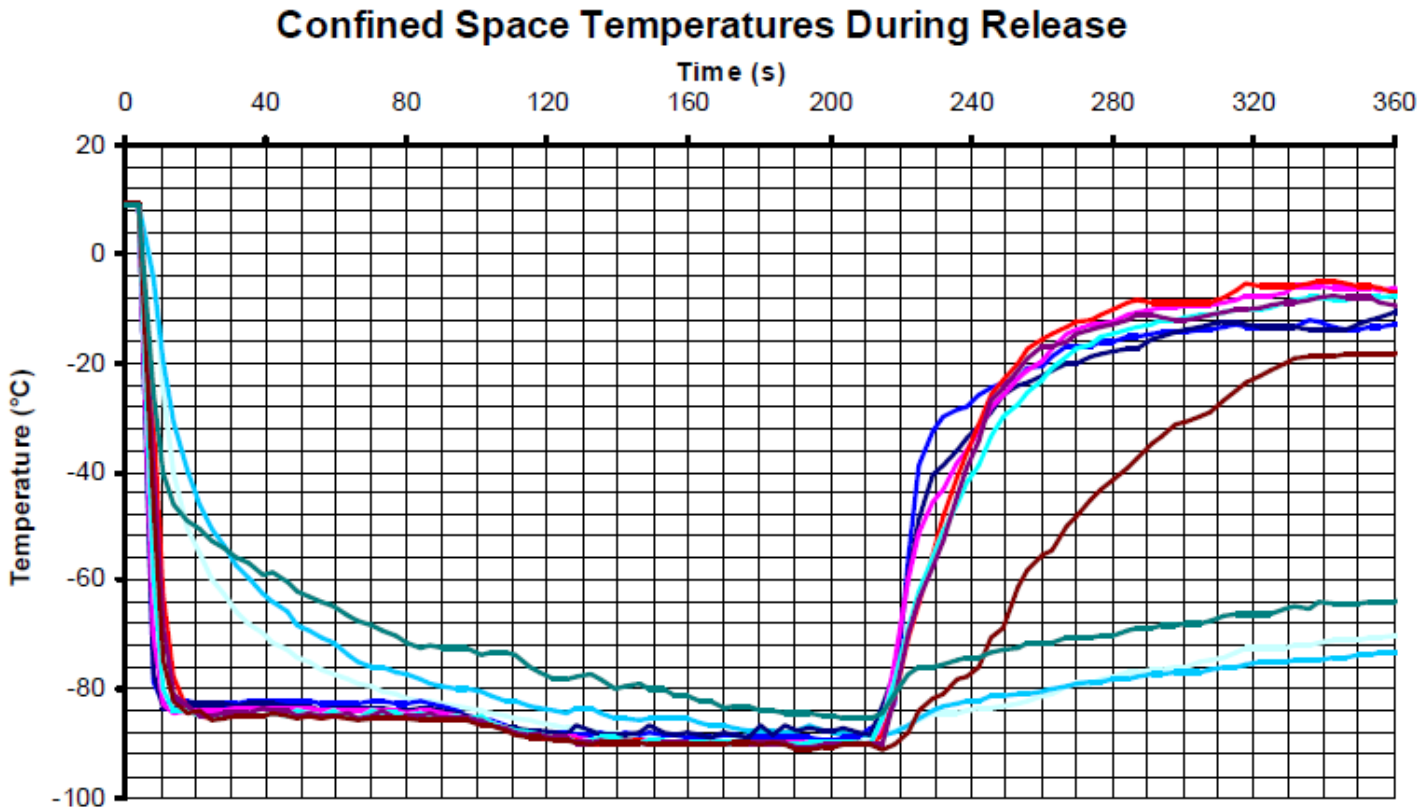


Photo and graph courtesy of the DNV CO2PIPETRANS JIP

Enclosed Space CO_2 Release



Photos and graph courtesy of the DNV CO2PIPETRANS JIP

Major Accident Regulation

- Major accident hazard industries have a duty to manage their major accident risks
- Very large CO_2 inventories within the CCS creates major accident risks
- CCS should operate within appropriate major accident regulation
- Having effective major accident risk management will support CCS growth

Concluding Remarks

- CCS CO_2 systems with large CO_2 inventories will have major accident potential
- Properties and behaviours of the CO_2 stream can cause or contribute to a leak
- Relevant hazard management processes can manage the major accident risks
- Appropriate regulatory oversight will help ensure safe operations

“There is no reason why the major accident risks from a CO_2 handling system within a CCS operation cannot be low and well within acceptable limits.

To achieve this will require the application of existing rigorous hazard management processes combined with an adequate understanding of the properties and behaviours of CO_2.”

[opening lines from the CO2RISKMAN Guidance – available free from www.dnv.com/ccus]

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