Carbon Capture and Storage
Health and Safety Issues
UK Regulator’s and Engineer’s Views

Slides courtesy of Rosemary Whitbread UK Health and Safety Executive with supplementary slides from IEAGHG

Presented by Mike Haines – for IEAGHG
Overview

- HSE’s role and the role of health and safety regulation in the UK
- Our interest in the CCS process
- Modelling the risks
- Controlling the risks
- Mitigating the risks
- Summary/conclusions
The role of HSE

"Our job is to prevent death, injury and ill-health to those at work and those affected by work activities"
What do we regulate?

- Occupational health and safety
What do we regulate?

- Work activities impacting on the health and safety of members of the public
What do we regulate?

- Major accident hazard sites
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- Major accident hazard sites
UK Regulatory Regime

- UK, safety legislation is “goal-setting” rather than prescriptive.
  - sets out the objectives that must be achieved
  - allows flexibility that may be used by companies to meet their statutory obligations
Principles for Regulating Major Hazard Industries

• Operators prevent major incidents so far as is reasonably practicable – compliance demonstration required under Major Hazard regulations
• Mitigation of residual risk (remaining when all reasonable measures taken) through:
  • Reducing the consequences
  • Protecting against harm using controls available in systems for:
    • Emergency planning
    • Land use planning (onshore)
The CCS Process

- HSE regulates the active process of capturing, compressing, transporting and injecting CO$_2$ into a storage formation
- HSE does not regulate the long term security of the store
Scaling up

The 30MWth oxy-fuel combustion pilot plant at Vattenfall’s Schwarze Pumpe Power Station in Germany
courtesy of Alstom Power
Scaling up

The 30MWth oxy-fuel combustion pilot plant [foreground] with Schwarze Pumpe power station, Germany [background]
courtesy of Alstom Power
Major Accident Hazard Potential of CCS

What we know:

- Capture technologies may bring large quantities known ‘hazardous substances’ onto power plant sites
  - e.g. amines, oxygen, hydrogen
- Exposure to high concentrations of CO$_2$ is known to be fatal
- A major pressure loss of dense phase CO$_2$ may result in additional hazards e.g.
  - cryogenic burns/embrittlement of neighbouring plant
  - toxic contamination etc.
CO₂ Incident examples

- **Industry**
  - CO₂ tank (30 Tonnes) BLEVE: 3 fatalities, 8 further injuries – Worms, Germany 1988
  - Leak from fire suppressant system: 107 intoxicated, 19 hospitalised, no fatalities - Monchengladbach Germany 2008

- **Geological**
  - Lake Nyos, Cameroon, 1986 – 1,700 fatalities, 1,600 kT release
  - Dieng volcano, Indonesia – 1979, 142 killed, 200 kT release
Lets not get carried away...

Lake Nyos ≠ CCTS Activities
Safety management: the bow tie approach

Prevention – reduce the likelihood of harmful event

Control & recovery – limit & mitigate consequences, re-instate
MSDS classifications

**CO₂**
- Label 2.2: Non flammable, non toxic gas.

**SO₂**
- TOXIC
- CORROSIVE

**H₂S**
- Label 2.3: Toxic gas.
- Label 2.1: Flammable gas.
- N: Dangerous for the environment
- T+: Very toxic
- F+: Extremely flammable
Modelling the risk: how harmful is CO₂?
Health effects of Carbon Dioxide

- **<1**: No effects
- **1-1.5**: Slight effect on chemical metabolism after exposures of several hours
- **3**: Weakly narcotic, deeper breathing, reduced hearing, headache, increased blood pressure and pulse rate.
- **4-5**: Deeper, more rapid breathing. Signs of intoxication after 30 minutes
- **5-10**: Breathing more laborious, headache and loss of judgement
- **>10**: Unconsciousness in under one minute, further exposure to high levels eventually results in death.

Typical 8hr exposure limit 0.5%
Typical STEL 3% (varies between countries)
Typical Human exhaled air

Oboe and Bassoon players breath analysis with time

Vol percent
- Oxygen
- Carbon Dioxide

Seconds
- 0
- 10
- 20
- 30
- 40
- 50

Vol percent
- 0
- 5
- 10
- 15
- 20
- 25

Slide origin IEAGHG
## Toxicity of CO₂ in context

<table>
<thead>
<tr>
<th></th>
<th>Carbon Dioxide</th>
<th>Hydrogen Sulphide</th>
<th>Sulphur Dioxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 minute exposure limit</td>
<td>15,000 ppm</td>
<td>15 ppm</td>
<td>5 ppm</td>
</tr>
<tr>
<td>8 hour exposure limit</td>
<td>5,000 ppm</td>
<td>10 pmm</td>
<td>2 ppm</td>
</tr>
</tbody>
</table>

Slide origin HSE
Impairment

- $\text{CO}_2$ can be tolerated in quite high concentrations without permanent risk to health
- BUT if those exposed have key tasks to execute their response may be impaired
- THUS need to consider effects during emergency situations

Atmosphere in submarines is typically 4000ppm CO2!! Just below the TLV. Crews should not be impaired. However levels up to 10,000ppm are reported
Modelling the Risk: areas of uncertainty

- Release behaviour of dense phase/supercritical CO?
  - Standard models do not consider phase change to/from solid
  - Experimental validation coupled with theoretical understanding needed

![Diagram](image)

**Assumed wind direction**

- **Jet**
- **Vapor/solid Mixture**
- **Entrainment of Warm, Moist Air due to momentum of the jet**
- **Gravity Slumping**
- **Solar Heat Gain**
- **“Gaussian” dispersion of the cloud**

**Entrainment of solid**

**Sublimation of solid from ground**
Phase changes in carbon dioxide

- Solid
- Liquid
- Vapour
- Dense phase
- Pipelines
- Critical point
- Triple point
Low temperature hazard

-56.6 °C 5.11 atm
-78.5 1 atm atmospheric sublimation point

Enthalpy

Pressure

Solid - vapour

Liquid - vapour

Isenthalpic expansion path

Typical Supercritical conditions

Critical pressure 73 atm
Critical temperature 31.1 °C

Risk of cryogenic burns, brittle failures and damage or injury due to abrasion

-78.5 1 atm atmospheric sublimation point

Slide origin IEAGHG
Pipeline Design – Key Issues to Avoid Pipeline Failure

- **Failure Frequency in Gas Pipeline Systems**
  - Influence of Pipe Diameter on the Leak Frequency

![Graph showing frequency of failures by diameter class.]

**Diameter class [inches]**
- Pinhole-crack
- Hole
- Rupture

**Frequency per 1,000 km-yr**

**Literature:** 6th EGIG Report, 2005
Pipeline Design – Key Issues to Avoid Pipeline Failure

- **Failure Frequency in Gas Pipeline Systems**

  - Influence of Pipe Wall Thickness on the Leak Frequency

![Graph showing frequency of leaks by wall thickness class](image)

**Legend:**
- Pinhole-crack
- Hole
- Rupture

**Literature:** 6th EGIG Report, 2005
Pipeline Design – Key Issues to Avoid Pipeline Failure

- **Failure Frequency in Gas Pipeline Systems**

  - Influence of the Year of Construction on the Leak Frequency

  ![Graph showing failure frequency per 1,000 km/year by year of construction](graph.png)

  **Reasons:**
  Improved welding, inspection, condition monitoring, improved procedures for damage prevention and detection (6th EGIG Report, 2005)

Literature: 6th EGIG Report, 2005
Modelling the Risk: areas of uncertainty

- Conditions after release?
- Cooling effect (brittle fracture?)
- Crack propagation
Modelling the Risk: areas of uncertainty

- Failure rate data
- Density implications
Controlling the risk: hierarchy for risk reduction

- **Eliminate**
  - Eliminate the hazard

- **Substitute**
  - Use processes or methods with lower risk impact

- **Isolate /Separate**
  - Segregate hazards and/or targets

- **Engineer**
  - Design to prevent an unwanted event/mitigate harmful consequences

- **Organisation**
  - Training, competency, communication

- **Procedure**
  - Operating procedures, permits, maintenance regimes, emergency response

- **PP E**
  - Personal Protective Equipment – protect the person
Controlling the risk: design & construction

- Reuse of existing oil & gas infrastructure
  - demonstrating fitness for purpose
- Assessing best practices in the absence of direct experience:
  - consequence prediction
  - probability assessment
- Demonstrating adequate risk control in absence of recognised standards:
  - maintaining primary containment (keeping high pressure/volume CO$_2$ in vessels & pipelines)
Controlling the risk

- Maintenance — continuing integrity
Controlling the risk: operation

- Safety management across the entire process chain
  - impact of process upsets
  - interface between different operators
Mitigating the risk

- Developing appropriate emergency response arrangements
  - understanding dispersion behaviour & hazard diameters
High vapour density

- Vapour accumulates in low points
  - Need to review layouts to identify areas at risk
  - Cold vapour has even higher density and will seek out low areas
- Need to consider pipeline routes
- Location of safe haven
  - Dilemma offshore – high or low on platform?
- Spill collection
  - Solid floors prevent CO₂ dispersion
Mitigating the risk

- Controlling development around installations and pipelines
Summary

- HSE considering the evidence to support extending the major hazard regulatory framework to the capture, transport and injection of CO₂ both on and offshore.
- Further research and early demonstration projects will remove some of the existing uncertainty but more work is needed.
- Collaboration is key, international standards and guidance will facilitate compliance demonstrations.
Key Message

HSE is a responsible enabler, working in the public interest to facilitate the safe introduction and proliferation of Carbon Capture and Storage.
The biggest risk?

CHANGE

Altering and adapting established designs and practices could be a significant contributor to accidents in the emerging CCS industry.
Thank you

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