Carbon Capture and Storage
Health and Safety Issues: a UK Regulator’s View
What do we do?

• Since 1911
• 350+ staff
• 550 acre site in Buxton, UK
• HSL set up to assist UK Health and Safety Executive (HSE) to minimise risks to people's health and safety at work
• Also work with a wide range of other public and private-sector organisations, conducting detailed, bespoke research and development work on their behalf.
What is health and safety?

• Occupational health and safety (boots & goggles)
What is health and safety?

- Work activities impacting on members of the public
What is health and safety?

- Major 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

Capture  Transport  Storage

+/- 1,000 km
Where does health and safety fit?

- Research/early concepts
- Planning permission/licensing
- Design and construction
- Operation and maintenance
- Decommissioning
- Long term stewardship

50+ years
Risk Assessment

CCS Process

What?

How low?

How many, how concerned?

How bad?

How often?

How big?

How much, how long, how far?
WHAT?
Credible hazard scenarios

- Identification of hazards at all stages of the CCS chain:

Capture/ Separation → Compression → Transportation → Storage

- Liquid Vapour Extraction (Scrubbing Systems)
- Pressure Swing Adsorption
- Membrane Diffusion
- Other Emerging Technologies
- Cryogenic Distillation

Compression
- Low pressure <40bar
- Intermediate Pressure 40 - 70bar
- High pressure 70 - 200bar
- Ultra High pressure >200bar

Transportation
- Pipeline
  - New: Gas Dense Phase Supercritical
  - Existing: Gas Dense Phase Supercritical
  - Grouped

Storage
- Low/Intermediate Storage (gas)
- High Pressure (gas/liquid)
- Cryogenic (Liquid)
- Road
- Rail
- Ship
CO$_2$ incident examples

- **Industry**
  - CO$_2$ 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
Let’s not get carried away!

Lake Nyos ≠ CCTS Activities
HOW BIG?
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
HOW MUCH, HOW LONG, HOW FAR?

Phase changes in carbon dioxide

Pressure, atm

Temperature, °C

-100 -80 -60 -40 -20 0 20 40 60

Solid

Liquid

Dense phase

Vapour

Critical point

Triple point

Pipelines
Release behaviour

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

• Heavier than air
HOW OFTEN?
Failure Rates

- Factors may include: component failure frequencies, component numbers, lengths, number of transfer operations, safety system failure probability etc.

Measurements
- Qualitative (often, seldom, rarely etc)
- Historic (databases etc)
- Predictive (fault trees, fracture mechanics etc)

➤ Chances per million per year
HOW BAD?
How harmful is CO$_2$?
How HSE Deals with MAH Toxicity

- **Evaluates:**
  - Exposure time x Concentration as a Dose or “Load”

- **Examines:**
  - relevant toxicity data to define the dose relationship equation

- **Specifies:**
  - the Load required to result in specified levels of harm or “Danger”

- **Publishes:**
  - the Dangerous Toxic Load (DTL) data (“A” value)
Setting the DTL

• The HSE Dangerous Toxic Load (DTL)
  ▪ Describes exposure conditions (concentration and time) causing a defined level of toxicity
  ▪ Used in Industrial Major Accident risk assessment
  ▪ Expressed as: \( ppm^n \cdot \text{min} = \text{DTL} \) where “\( n \)” is an exponent

• Specified Level of Toxicity (SLOT) DTL:
  ▪ severe distress, many people need treatment, some hospitalised, occasional deaths

• Significant Likelihood of Death (SLOD) DTL:
  ▪ 50% mortality in exposed population
Setting the DTL

- Level of toxicity matching SLOT criteria seen at 7.5% for 15 min
- Conservative estimate of conditions causing 50% mortality is 17% for 35 sec
- Taking ‘n’ in the ppm$^n$.min relationship as 8 has a good fit with the data
- SLOT DTL = $1.5 \times 10^{40}$ ppm$^8$.min
- SLOD DTL = $1.5 \times 10^{41}$ ppm$^8$.min
### Toxicity of CO\(_2\) in context

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

• Conditions after release?
  – Cooling effect (brittle fracture?)
  – Crack propagation
HOW MANY, HOW CONCERNED?
Populations around installations
HOW LOW?
Safety Management

Likelihood

- Hazard
- Threat
- Barriers

Consequence

- Scenario
- Consequence
- No escalation
- Full escalation

Prevention – reduce the likelihood of harmful event
Control & recovery – limit & mitigate consequences, re-instate
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

- **PPE**
  - Personal Protective Equipment – project the person
Controlling the risk: design and 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 \( \text{CO}_2 \) 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: emergency response

- Developing appropriate emergency response arrangements
  - understanding dispersion behaviour & hazard diameters
Mitigating the risk: populations around installations
Conclusions

• Toxicity of CO$_2$ gives it larger hazard ranges than for asphyxiation alone.

• Some uncertainty remains over supercritical releases.

• There are no major showstopper associated with the CCS process (initial studies show roughly comparable risk versus distances for gaseous CO$_2$ and natural gas).

• The aim here is to raise awareness so that health and safety issues can be addressed in design, operation and emergency response.
Thank you

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