Breakout Session 2
Identifying Knowledge Gaps

- **Within Discussion Topic:**
  - Discuss knowledge gaps and identify needs of the R & D and wider CCS community.
  - Discuss how Networks can assist in meeting needs of the R & D and wider CCS community.
  - Identify areas requiring input from more than one Network
  - Discuss if there is a need for Networks or ad-hoc workshops in other key areas

Uncertainty in simulations forming parts the permits (e.g. risk assessment, reactive transport in storage reservoirs). Model updating (history match) consequences for validity of operation license?	**Completeness of observation and quantification of leakage, especially in shallow and surface monitoring. (Public wish for a guarantee, that there is no risk and any deviation from planned behaviour can be detected before damage occurs)**	**Corrective Measures Plan/ Remediation Plan**	**Monitoring Plan – site specific and based on risk assessment and potential migration pathways**	**Protection of shallow groundwater resources, especially against displaced brines from saline aquifers.**	**Link between monitoring results and (mandatory) operational consequences (e.g. thresholds, conditions for site abandonment)**
Anasazi South	**Zia A**	**De Vargas**	**Zia B**	**Anasazi South**	**Zia C**
Rajesh Pawar	Charles Jenkins	Hubert Fabriol	Franz May	Katherine Romanak	Sue Hovorka
Jeremy Rohmer	Bill Carey	Stefan Bachu	Lee Spangler	Neil Wildgust	Angeline Kneppers
Tom Daley	Matt Gerstenberger	David Borns	Marion Børresen	Thomas Hughes	Ernie Perkins
Sevket Durucan	Bernard Giroux	James Houseworth	Sarah Hannis	Michael Kuehn	Kevin Dodds
André Garnier	Ken Hnottavange-Telleen	Thomas Le Guenan	Randy Locke	Philip Stauffer	Julianna Fessenden
Justin Jayne	Dennis Newell	Jim Sorensen	Yuji Nishi	Rob Trautz	Neeraj Gupta
Michael Krause	Brian Strazisar	Ron Sweatman	Masao Ohoka	Hans-Dieter Vosteen	David Lumley
Hidemitsu Shimada	Marianne Walck	Carmen Dybwad	Ji-Quan Shi	Elizabeth Keating	Henk Pagnier
Nobukazu Soma	Melissa Fox	John Hamling	Makiko Takagishi	Robert Van Voorhees	Arie Verdel
Ed Steadman	George Guthrie	Theresa Watkins	Joanna Thomas	Udo Weyer	Max Prins
Tim Tambach	Anna Korre	Andrew Duguid	Don White		
Peter Wyant					

Uncertainty in simulations

Knowledge gap 1: specificities of CCS

- **Issue wider than CCS**
- **Approaches / methodologies exist and lessons** can be learnt from other communities (e.g. Oil & Gas, nuclear)
- **But specificities issues** of CCS in terms of:
  - knowledge / information amount
  - Wide spatial scales (e.g. pressure-impact zones)
  - Time dependency: e.g. temporal evolution of risk profile
  - Public perception

Uncertainty in simulations

Knowledge gap 2: model uncertainty

- Not only a matter of knowledge gathering, but also how to **adjust** / re- do model concepts in the light of new knowledge ➔ iterative process
- Balance between sophistication, number of parameters, increase of number of uncertainty sources: **what is enough ?**
- **How to integrate model unc. in the permitting process?**

Uncertainty in simulations
Knowledge gap 3: communication

- **Communicating** uncertainty on the results / knowledge to
  - Public
  - Regulators

  ➔ communication approaches may differ depending on the background of each audience

Uncertainty in simulations Needs

- Current no consensus➔ need for systematic / robust approaches for iterative link between statistical-based procedure, risk assessment, monitoring, verification: **best practices in CCS**
- But these should be flexible ➔ **reservoir specificities matter**
- Systematic sensitivity approaches: Model➔ identify key parameters ➔ iterative process with characterization phase
- Dealing with uncertainty ➔ dealing with consequences ➔ **mitigation plans**
- Unc. Treatment approaches exist, but need for **validation through application**
- **Better understand the need of public / regulation**

Uncertainty in simulations
Connection with other networks

- Risk assessment : how to communicate on uncertainty
- Monitoring

Uncertainty in simulations
Potential Future Workshops

- Communication with wider stakeholder (public/regulators) group on handling Uncertainty
- Lessons learnt from the application of different approaches (e.g. In-Salah)

Completeness of observation and quantification of leakage, especially in shallow and surface monitoring.

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quantification

Knowledge Gaps

- Definition of leak
  - Current regulation not realistic (“no leakage”)
  - Need to include *CO_2, brine, hydrocarbons*
  - Redefine in terms of impacts
    - Receptors must be defined
    - Does not address carbon credits
  - Leakage should be qualified (“detectable”, “significant”)
  - Current regulation requirements will change with technology
- Attribution is a key requirement: is this adequately understood?
  - Integration of diverse data sets may be necessary
  - Determining the source of the leakage
    - Wells, fractures, caprock, spills, migration
- How do we know when we’ve adequately characterized the baseline?
- Completeness includes accounting for other potential actors impacting groundwater
- 99% sequestration criteria in US is fundamentally impossible to meet
  - Cannot “prove” that the CO_2 is in the reservoir
  - Cannot “prove” that less than 1% has leaked (blanket observation)
- Impacts, by definition, can already be measured
- *Proving* carbon sequestration for credits is effectively impossible
- Monitoring at depth, while expensive, may allow remediation before impacts occur in the shallow subsurface
- Off-shore monitoring methods and approaches

quantification

Potential Network Activities

(Environmental impacts, Monitoring, well integrity)

- Attribution (Interpretation of Monitoring Data)
  - Determining origin of potential leakage in complex and realistic situations
    - CO_2, brine, mobilized hydrocarbons
    - Test on analog sites—e.g., CO_2 EOR sites
  - Development of new theoretical and analytical methods of attributing leakage
  - Determining most effective monitoring method
    - Soil gas, array of shallow monitoring wells, satellite or laser based methods
    - Controlled-release sites are essential
- Determine variability of aquifer response to CO_2
  - Passage of fronts, buffering capacity, metals
  - Understand how a laboratory characterization of drinking water aquifer (core samples) relates to likely impact of CO_2
- Understand difference between confined and unconfined aquifers
- Development of methods that can monitor large areas effectively
  - Satellite hyperspectral data, ground-penetrating radar, electrical resistivity
  - Optimized with on-the-ground measurement
- Team with new work on methane leakage attribution
- Team with work on off-shore gas detection
- Perhaps difficult to motivate research on baseline variability

Corrective measures plan/remediation plan

1- Distinguish deep reservoir and shallow aquifers

In the reservoir :

- the plume doesn't go where as predicted (but we have to take into account the real reservoir complexity),

- pressure increase above the allowed limit,

- wells failure

- leakage from unknown flow pathways (e.g. bubbles coming out at the reservoir)

Shallow subsurface:

- see Franz Liszt of potential impacts: soils-aquifers-

Corrective measures plan/remediation plan 2 preliminary remarks about wells and shallow subsurface

- Repairing leaking wells : Existing experience from industry is much far from what we really need in CO2 storage (or requires the help of well integrity Network)
- Shallow groundwaters: remediation of contaminated shallow groundwatyers is a standard practice

- Regarding communication with public, be careful to in saying that has been resolved in other domain (in part because of industry confidentiality). X Cross-cutting issue with the other NW

Corrective measures on deep reservoirs

- *1st: know that there is a problem, 2nd: characterize the problem (for where it is exactly see Monitoring NW), 3rd: setup the specific actions*
- *pressure management: stop injection, produce CO2, water (what to do with it?), reinject them to create a pressure barrier*
- *changing flow direction, change permeability (using chemical treatments to change relative permeabilities to different fluids) already used in EOR, there is a lot of expce there*
- *biofilms*
- *what about the caprock?. Could be a fracture or a linear structure (sand channel). Inject a gas cap over the CO2 to play with different wettabilities*

*- depending on the characterization the O&G industry has solutions for each case …**

The problem is the cost and the willingness to pay for that … but if water resources overlaying could be damaged (actions proportional to the impacts) you have to think what is the best solution (be careful with communication aspect with public)

- breakthrough technologies: be careful in injecting exotic species in the reservoir because you will to explain that to th public

- What are the criteria to start action?

Set a metrics for action

- The RA NW should say when there is a risk and the Monitoring NW should detect when there is an irregularity and when the damage is fixed

- Metrics will be site specific, how far ? How it will be possible to standardize this? As well corrective actions will be site specific.

- Up to now we don't have experience of repairing a damaged reservoir

1st question: => the main problem is to know that we have a leak, but there are always limitations to our technologies, investigate why sometimes it may fail

2nd question:

- the RA NW is a critical component for the ID of the gaps. It is true risk assessment to define what we do not know

- regulators need to have the same level expertise of the operators themselves to understand what they are told about . The NW can help the regulators to have this expertise to understand what they need to understand.

- IEA GHG launch a study on migration & remediation actions on unwanted CO2 migration and irregulalities (BRGM coordinator with IRIS, CO2GEONET members)

3rd: other networks in leakage detection, evaluating impacts, evaluating the benefits of the corrective actions

4th question

- Need for a dedicated workshop, not a specific network

- Sharing experience with the O&G world, bring people from other areas

- The scope of the risk assessment network should be expanded to risk management (including corrective/remediation plan)

Monitoring Plan – site specific and based on risk assessment and potential migration pathways

Knowledge Gaps

- Relationship of geophysical data to actual CO2 and geological parameters. Site specific calibration needed
- Detection vs quantification and how quantitative is quantitative enough
- Are there key indicators that indicate escape that might not be quantitative?
- Better understanding of physical and chemical transport processes (e.g. if secondary pooling is common, seismic could be effective for leakage monitoring) – Can we learn from natural gas experience?

Knowledge Gaps

- No general recipe - How have existing projects needed to adjust monitoring plans
- Generally accepted Risk profile and knowledge profile are mismatched – does this dictate more monitoring initially or less until we can intelligently place monitoring?
- Integration of various monitoring purposes represents a challenge – regulatory environment is part of site specificity

Network Comments

- Risk Assessment needs more interaction
- No general recipe
- Workshop drawing from all networks might be useful
  - What monitoring is needed to improve model
  - What model outputs are needed to refine risk assessment
  - What environmental consequences would be highest concern?
- Or co-convene network meetings (Monitoring & Modeling, Modeling & Risk Assessment, or all three)

Groundwater Protection Knowledge Gaps

- How do we address site specific nature of groundwater protection? No one prescriptive answer for each site. (MON, MOD,WB, RA, EI)
- How can we integrate and apply knowledge from various research techniques to predicting impacts (Natural analogues, Controlled releases, Lab experiments, Industrial analogues) (MOD,MON)
- How do we assess the outcome of exogenous fluids entering a shallow aquifer

Groundwater Protection Knowledge Gaps

- With need for complete hydrogeochemical characterization how do we manage effort with reward ?
- How to separate natural impacts or those from other industry from those induced by CCS activities

- What is the nature and extent of migration of fluids (brine and CO_2) (RA, WB, MOD)
  - Extent to which a release will enter and impact an aquifer (intermediate interceptors, buffering)
- How do we monitor? (sensitivity, background variation, best parameters) (MON, MOD)
- How to determine contaminants of concern (competing substance: brine CO2, organics, metals)) (MON, MOD, EI)
  - Impact
  - Remediation
- Persistence of impact.) (MON, MOD, EI)

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Workshop

- Use one site
- All networks assess
- Share data
- Have a workshop

2nd Joint Network Meeting

6. Link between monitoring results and (mandatory) operational consequences (e.g. thresholds, conditions for site abandonment)

Definition of topic and scope

A trigger (we have measured something that merits attention, not necessarily an event we have to deal with: deviation from model (a mode is a range of 'normal' variability): continuously reassess your trigger (iterative assessment of trigger and range): establishment of proper criteria. Ongoing learning process.

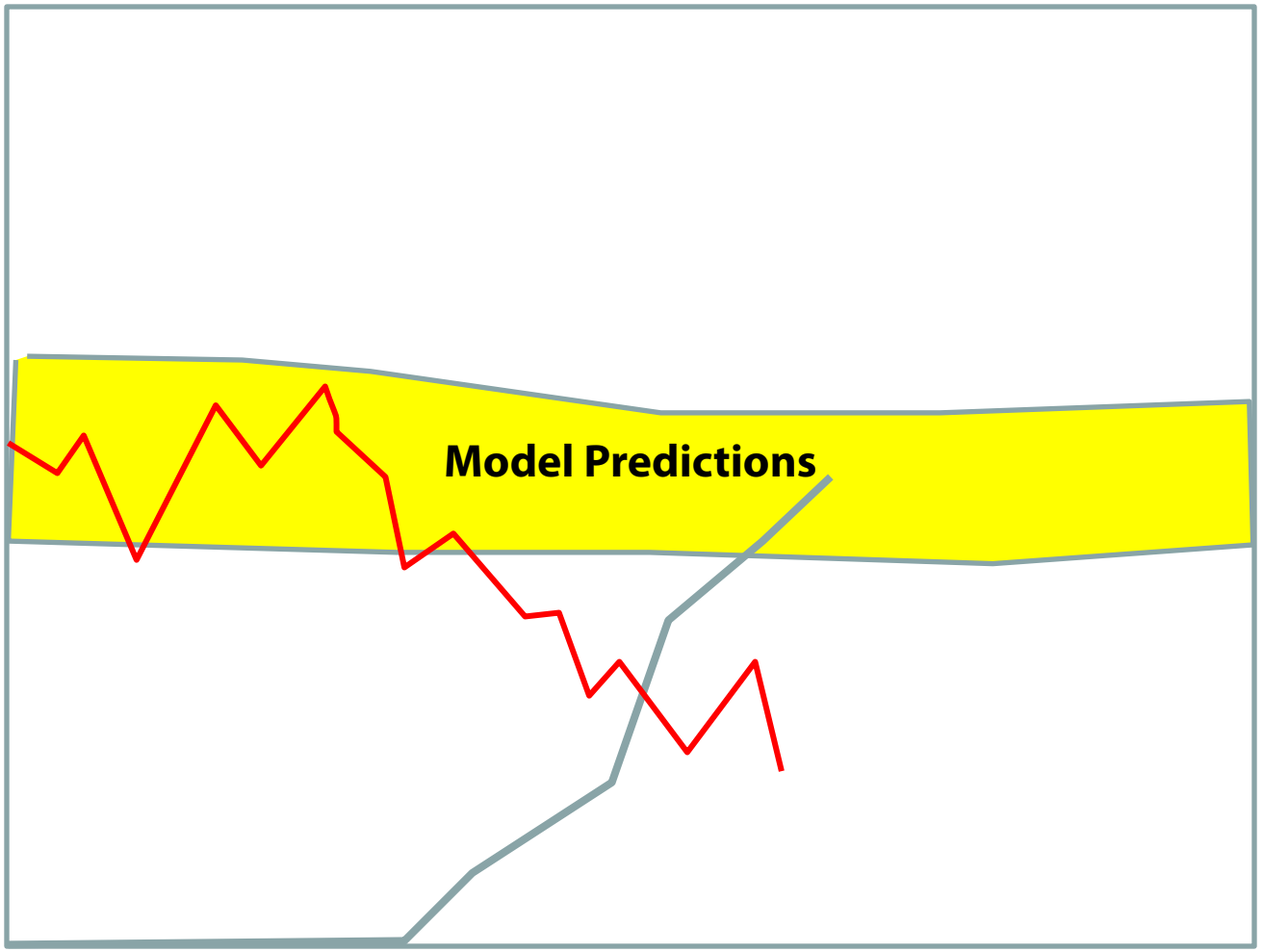
An event (leak, realization of the risk): further investigation.

- Trigger based on results
- Research or Commercial Operation?
- Is it in the reservoir complex? Monitored but not as extensive, backed up with some geophysics
- Is it outside the reservoir complex? Major difference.
- Define criteria of performance: if not carry out an action
- Define compliance
- Agreed risk is essential : different risk definitions and profiles, build on this – major differences between regions – to build a robust plan.

Challenges

- Risk and their analysis
- Monitoring defined to address perceived risks (uncertainty, resolution, quantification…)
- Monitoring tied to the operation (safety protocols of normal operations vs what can be addressed through monitoring: large volume going in+PE: restrict discussion to actions related to leakage of CO2)
- Process/systematic way of going through uncertainties as you move forward
- **Define Expectations: define criteria/thresholds and 'acceptable' deviation form trends. Define model vs expectations**
- **Define Reporting (when, what, how to report deviations from plans)**
  - Regulator (environmental)
  - Operator (O&G)
- Define conformance vs non conformance
- Define performance, and when/what action to carry out
- Update monitoring plan and reporting on a regular basis
- Mitigation/remediation options

e.g. Sue's diagram


Monitoing Parameter
Model Predictions
Injection mass
Time

Research focus and message to regulator

It's a well managed process – comprehensive iterative process: improve or change

- Tools getting better and new ones : tool responses
- Geological uncertainties more and more understood
- **Improving integration of risk with project process/performance**

Focus:

- Categories of monitoring to set trigger boundaries: required
- Define triggers of your operation: how significant it has to be
- Continued improvement of existing monitoring technologies and development of new technologies
- Risk driven research (still requires to define the risks and the process)

Conclusions

- Define a plan, model and criteria with regulator
- Define when, what to report and how to report/ check boxes
- If not how to get back into compliance - to be redefined
- Don’t get caught in a way you can’t meet the plan/expectations
- Peer reviews when not comfortable with process: going back and forth as in its infancy: set expectations

Recommendation:

- Meeting how more mature industries report on this