Monitoring Summary

Kevin Dodds
BP Alternative Energy

Susan Hovorka
BEG/UT

Japan 2009

Natchez 2010

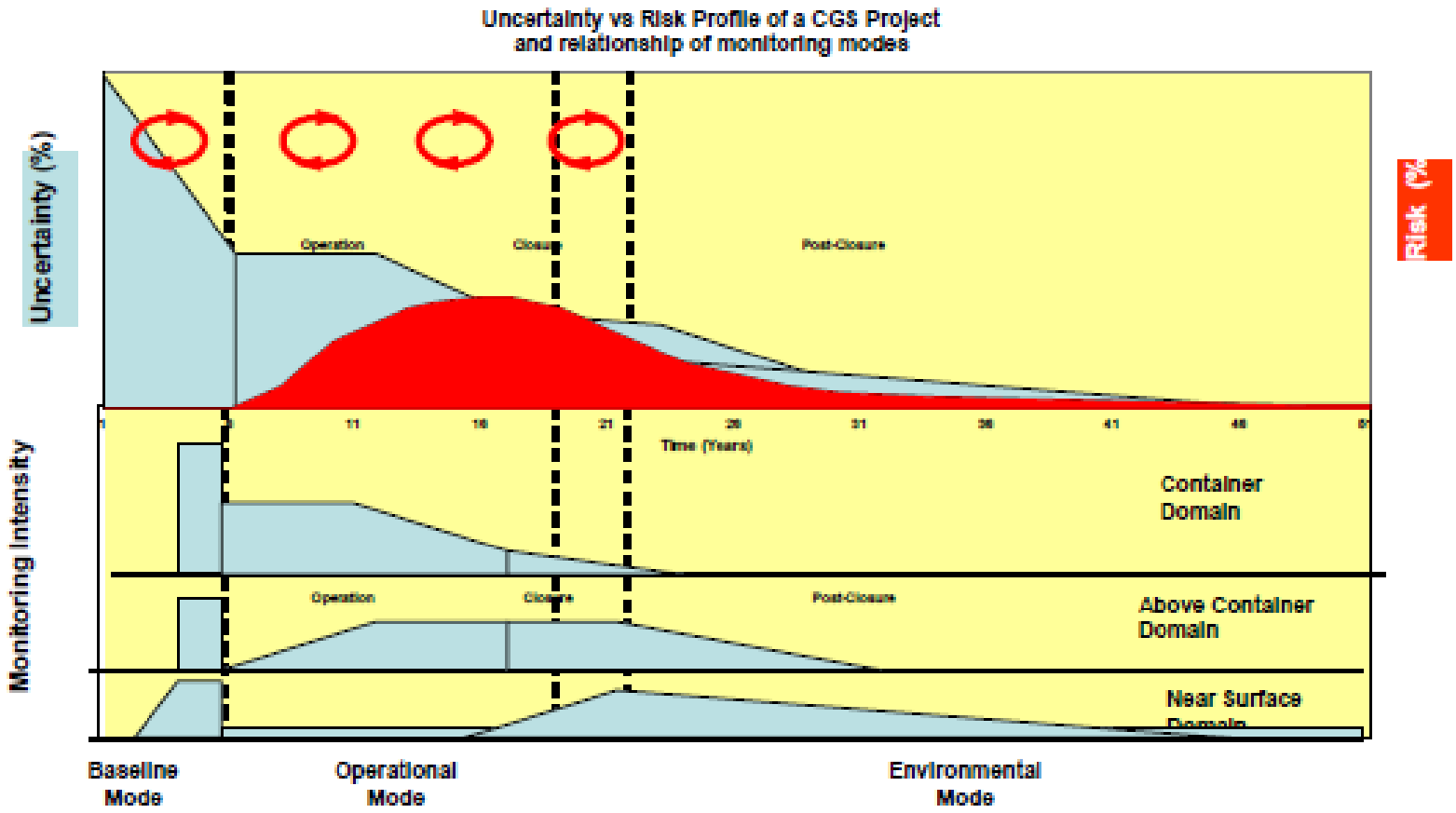
Potsdam 2011

- Key Categories
  - Regulatory
  - Management
  - Technology
  - Challenges

Joint Network New York

- How have we scored

Risk Profile



Risk Network Colorado 2010 Kevin Dodds BP AE

Tokyo 2009

International Monitoring Projects

- Ketzin, Germany
- Lacq Rousse, France
- Gorgon, Australia
- Update ETI monitoring review, EPA BEG CCP monitoring study

What Regulators Want

- EPA Victoria and CO2CRC – Panel discussion
- Regulation of EU and US state regulations

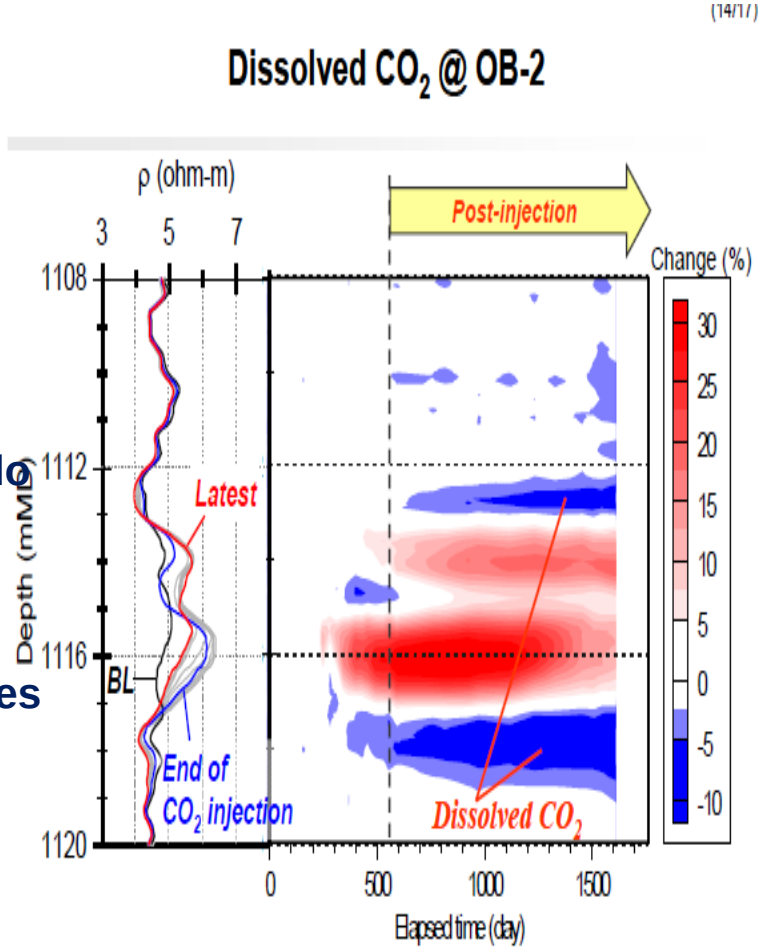
Reality Check – What monitoring can and can't do

- Quantification
- Otway atmospheric and soil monitoring
- Strengths and weaknesses

Emerging and Innovative Monitoring Technologies

- InSAR
- Real time integrated monitoring
- Electrical monitoring
- Thermal monitoring

Visit Nagaoka site



Conclusions 2009

- Learn through pilot projects
- Leakage “innocent until proven guilty”
- Challenge in momnitoring edge of plume, imaging and/or pressure
- Monitor geochemistry
- Multiscale data sets

Natchez 2010

- **Reports from Projects Networks and Research**
  - Risk assessment and Environmental Impacts workshop
  - CO2Remove and Otway
  - What we have learnt
  - Ketzin and RCSP
  - Feature Japan and CCS projects
- **US and Canadian projects**
  - US partnerships LBNL/DOE
  - SECARB Cranfield BEG
  - PCOR MVA activities EERC
  - WESTCARB and NRAP
  - MRCSP field demonstration
  - Microseismic monitoring in Aneth field

Panel discussion on Dealing with Uncertainty

Andy Chadwick BGS

Regulatory.

US EPA mandatory reporting
EOR and CCS Policy progress US
Strengths and weaknesses

Emerging Technologies

In Salah Geomechanics (InSAR)
Monitoring ECO systems RISCS Project in UK
Geochemical effects of injection AIFT
Electrical Resistivity Results Cranfield

Visit Cranfield

Conclusions 2010

- Risk
  - Integrate process risk-monitoring-mitigation
- Monitoring and modelling
  - Hisory matching –how close ?
  - Geomechanical interpretation
  - Faster iteration
- Well Integrity
  - Cement quality important
  - MMV cement inspection
- Permanent installations
  - Instrumentation
  - Question of dealing with negatives

Potsdam 2011

Review and Performance of Monitoring Tools

- 4DVSP and 4D Seismic CO2CRC/CCP
- Seismic at Ketzin
- Nagaoka 4D Seismic
- Geoelectric measurements at Ketzin
- Pressure monitoring at Cranfield
- Phase status pure and impure CO2 fluid rock interactions
- InSAR geomechanical Inversion, summary of LBNL/LLNL work.

Demonstration of No Leakage

- Recent IEAGHG Studies
  - Quantification of leakage Imperial College
  - Monitoring of mobilised substances CSIRO/CO2CRC

CCS in the CDM

Data Integration how monitoring conforms with modelling

Geophysics and Geochemistry
Marine Gravimetry Sleipner
Near well bore characterization PNG and DTS GFZ Ketzin
Geophysical modelling from geoelectric and seismic GFZ Ketzin
History matching Otway
History matching Ketzin
Discussion Conforming with modelling Data

Potsdam 2010 (contd)

Current and future activities in permanent installations

- Gasgeochemistry in Ketzin
- Baseline atmospheric monitoring CO2CRC
- Site closure assessment CO2CARE GFZ
- CO2 field laboratory Norway

Protocols and Strategies to form monitoring plan

- Shell Quest and GoldenEye
- Strategic Discussion BGS Chadwick

Monitoring saline waters

- Conductivity measuring brine movement UT
- Saline Water Leakage Natural Release UT
- CO2 Intrusion in shallow aquifers University of Kiel

Soil Gas and atmospheric

- A New approach to Soil-Gas Monitoring: Katherine Romanak, University of Texas
- Testing Atmospheric monitoring techniques (mobile laser and eddy covariance) at natural and made made leakage sites and In Salah: Sarah Hannis, BGS

Conclusions EU Storage Directive Minimum conditions for closure Chadwick

- Plume conforms with modelled behaviour
- No detectable leakage
- Storage Site is evolving to long term stability

Joint Network New York Questions

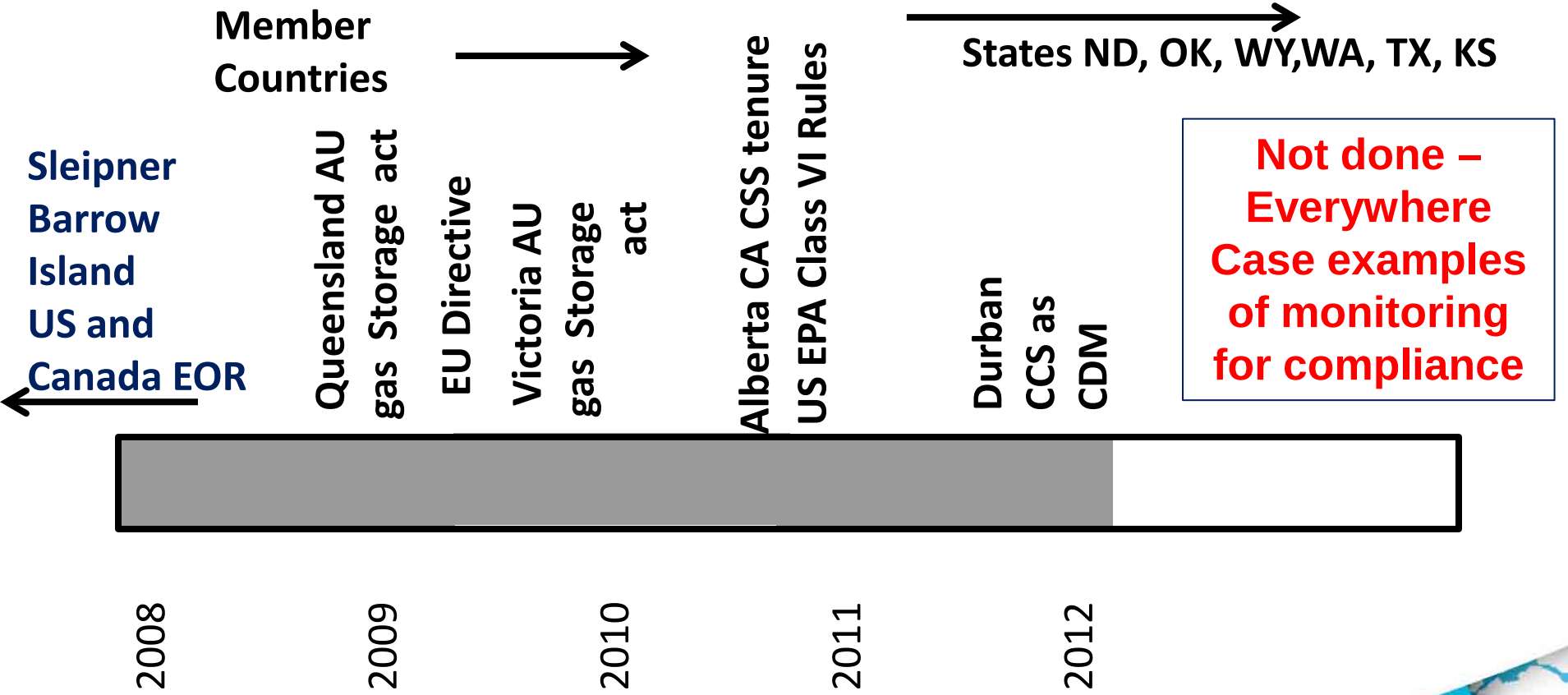
- **Definition of Monitoring**
  - Process to identify purpose
  - Who are the customers
  - Matrix of monitoring tools
- **Quantificatio**n
  - To what degree of sensitivity?
  - To what degree of certainty?
  - What measurements to address these
  - To what degree of integration
- **Screening technologies by regulatory regime**
  - Emissions accounting
  - Storage security
  - What technologies suitable to answer questions
  - What accuracies, thresholds etc

Storage security without quantification

One strategy is to concentrate your monitoring at the reservoir and immediately above in seal and porous zone
Requires mitigation plans in place
Reduces near surface monitoring to public assurance role
In the case of leakage we then need to apply additional monitoring.

Progress on Definition of Monitoring

- Regulatory environment has advanced – expectations much better defined, but not mature



Progress on Storage Security without Quantification

Sleipner
Weyburn
West Pearl Queen
Nagaoka
Frio 1&2
InSalah

- **Field tool demonstrations advanced**
  - **Existing tools effective for CO_2**
  - **New tools developed**
  - **Advance protocols developed – QUEST, Gorgon Goldeneye etc.**

ZERT field test

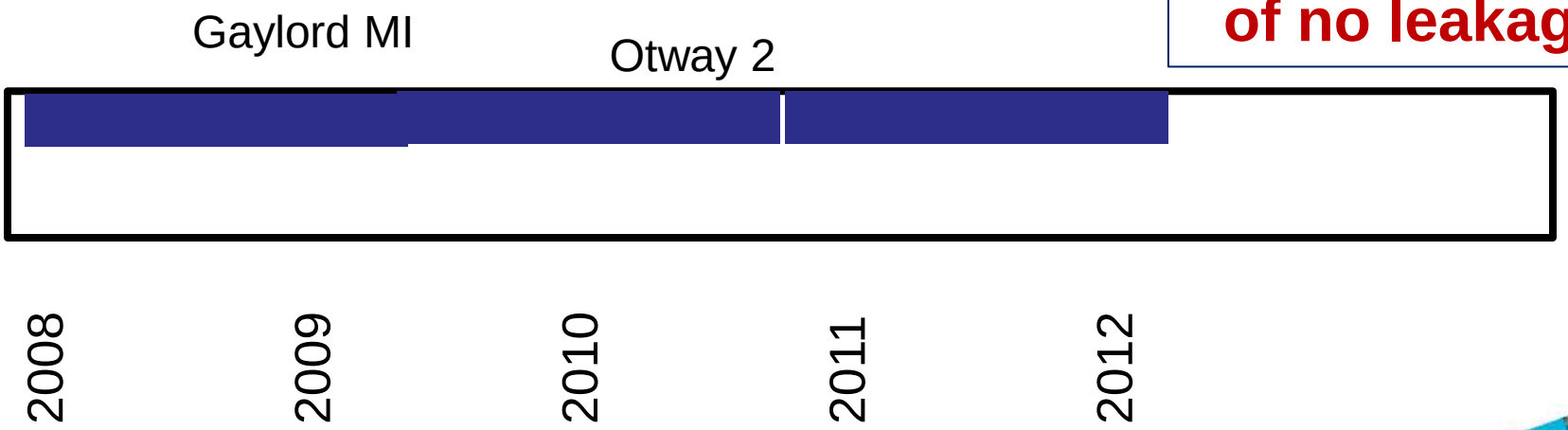
Otway

SECARB Cranfield

Ketzin

Projects in China?
Illinois ADM

Not done – Effective demonstration of no leakage



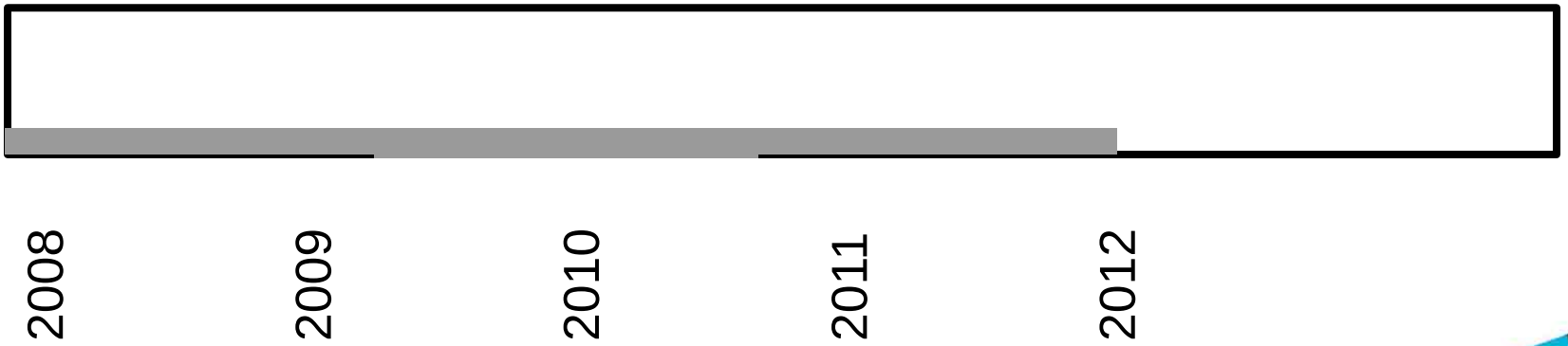
Progress on Leakage Quantification

- Field tool demonstrations advanced
  - Good progress showing limits of precision

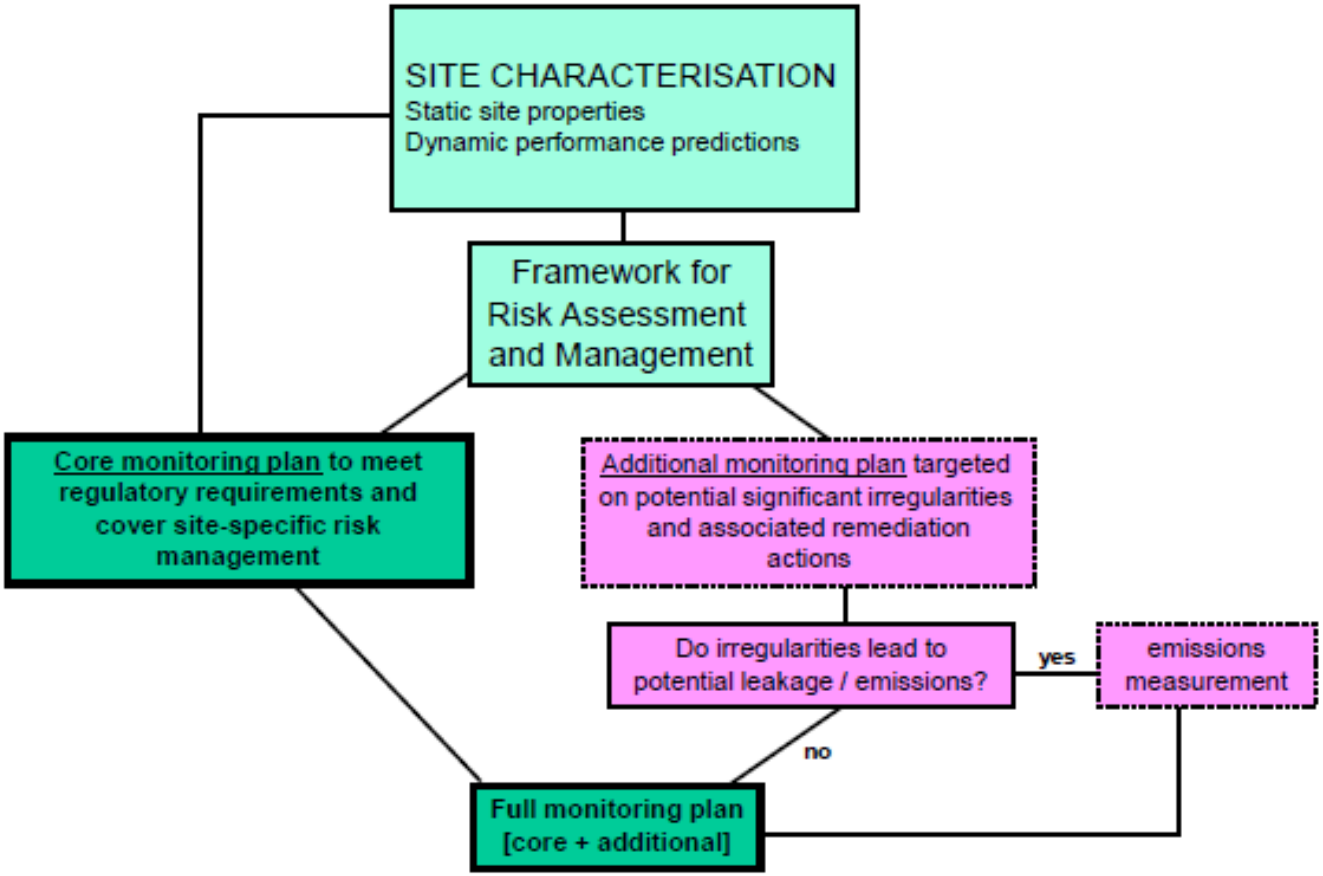
Sleipner
Weyburn
West Pearl Queen
Nagaoka
Frio 1&2
InSalah

Not done – Effective leakage quantification

SECARB Cranfield
Ketzin
ZERT field test
Otway
Gaylord MI
Illinois ADM
Otway 2

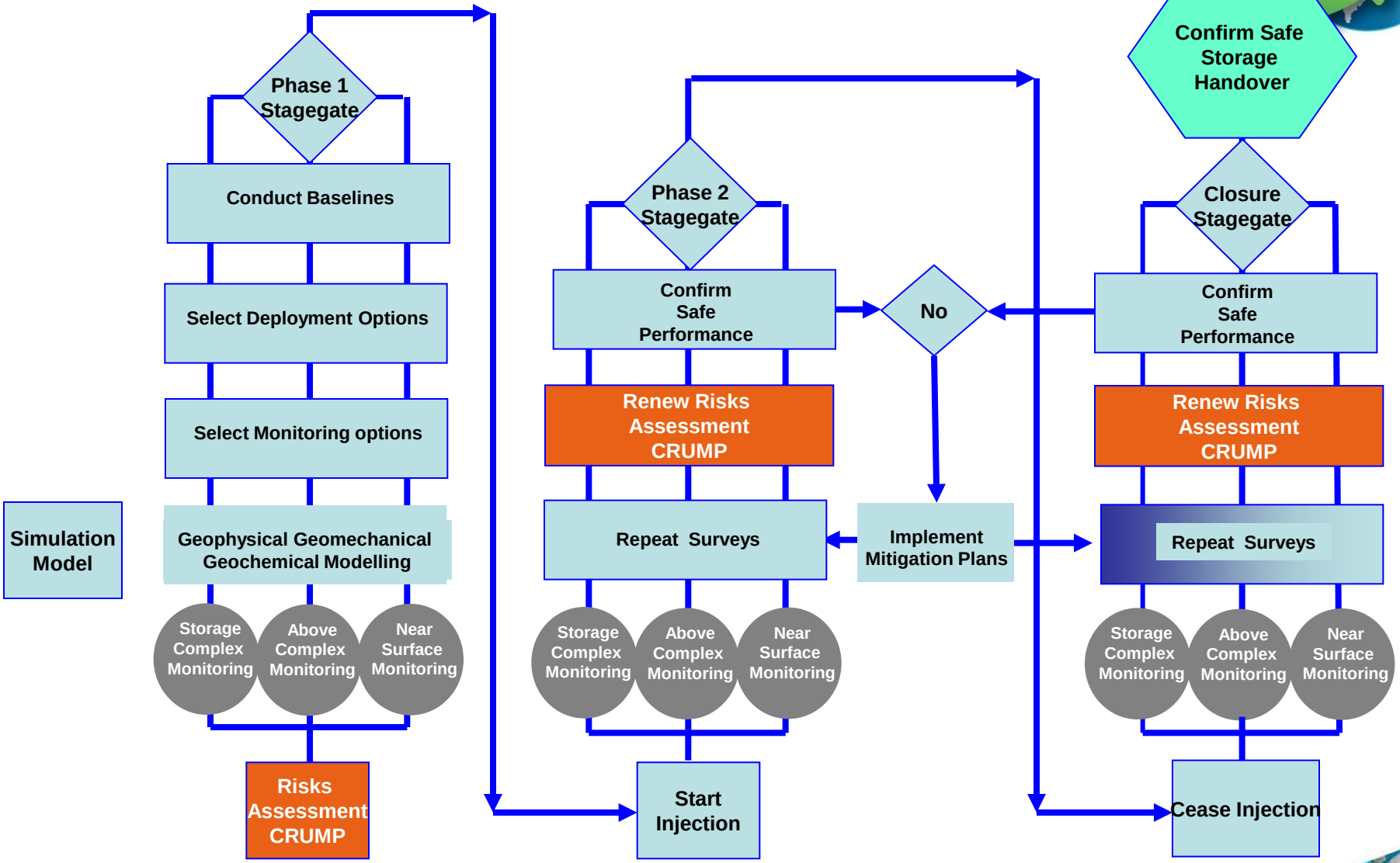


Monitoring Strategy flowchart



- Protocols and strategies for a monitoring plan Andy Chadwick, Rob Arts, Jonathon Pearce and Dave Jones Potsdam 2011

Monitoring Functional Ladder

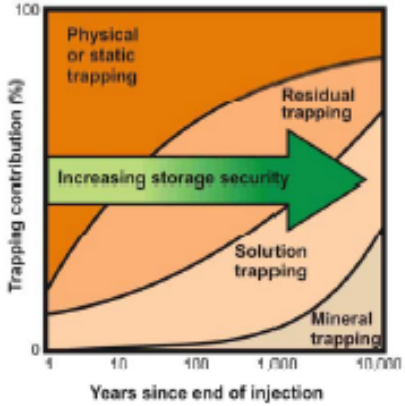


Diversified Monitoring Program Eliminates Dependence on any Single Technology

Managing uncertainty

Actual behaviour of the injected CO_2 conforms with the modelled behaviour

- Need demonstrate basic understanding
- Uncertainty will not lead to future divergence



No detectable leakage

- Monitoring tools have finite detection thresholds
- Need to accept site characterisation i.e. 'innocent until proven guilty'

Storage site is evolving towards a situation of long-term stability

- Need to demonstrate onset of key stabilisation process
- Analogue data from pilot-scale or similar sites