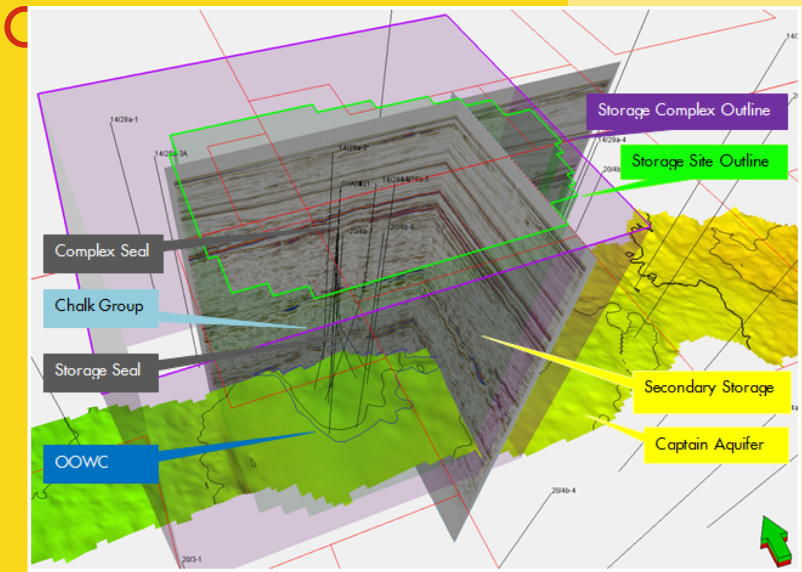
THE GOLDENEYE MMV PLAN FOR THE PETERHEAD CCS PROJECT

RISK-BASED MONITORING FOR A DEMONSTRATION PROJEC



10th CO2GeoNet Open Forum

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11 & 12 May 2015, Venice

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OVERVIEW

- Peterhead CCS Project & Goldeneye Storage Complex
  - Project and storage complex overview
- Risk-Based Measurement, Monitoring and Verification (MMV) Plan
  - Objectives (Ensure Conformance and Containment)
  - Identified Threats and Evaluation
  - Bowtie Method, the Goldeneye Bowtie
  - Base Case Monitoring, Contingency, Corrective Measures and Post Closure Plans
- Front End Engineering Design (FEED) Phase & the MMV Plan
  - Challenges/Risks: costs, operational constraints, data management
  - Opportunities: emerging technologies (4D DAS VSP)
- Summary

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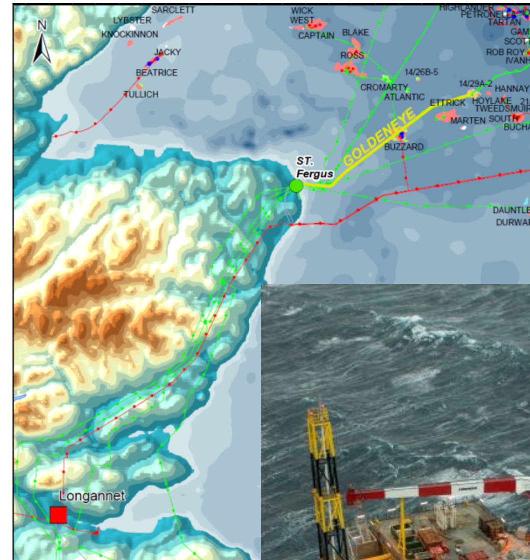
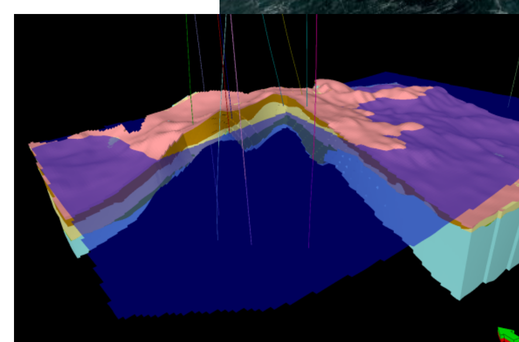
PETERHEAD CCS PROJECT
GOLDENEYE STORAGE COMPLEX

OVERVIEW

PETERHEAD CCS PROJECT

- **World First** – first full-scale CCS project on a gas-based power station
- **Where** – capture at Peterhead Power Station; storage in depleted Goldeneye gas reservoir (100km offshore North Sea, at a depth of more than 2km)
- **Impact** –At least 10 million tonnes of CO_2 emissions captured over ten years
- **Funding** – UK Government support for both capital & operating expenses
- **Technology** – post-combustion capture using amines
- **Status** – February 24, 2014 Shell and UK Government signed agreement allowing project to enter the Front-End Engineering Design (FEED) phase which is expected to last until 2015





GOLDENEYE STORAGE SITE & COMPLEX

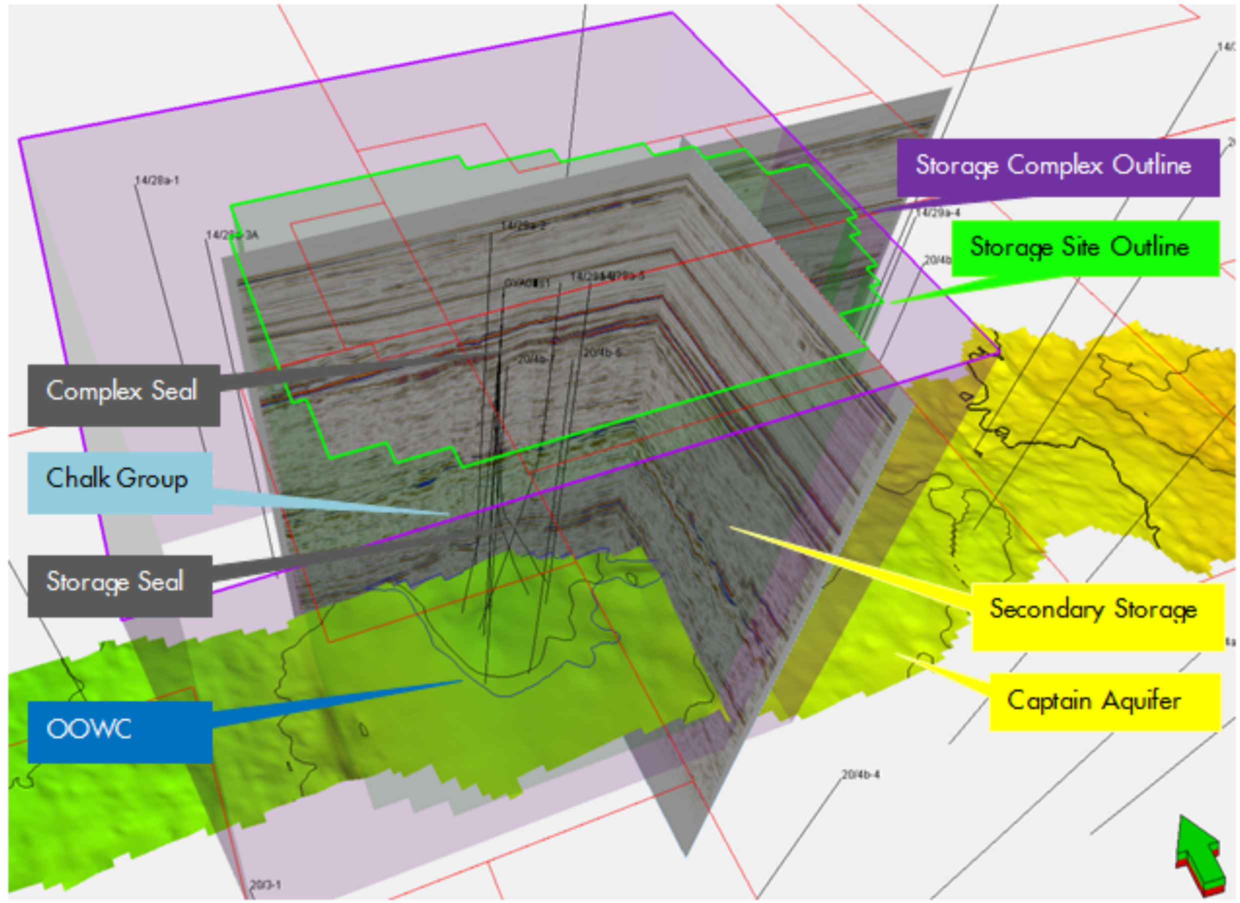
- Storage site (green): Volume area within a geological formation used for the geological storage of CO_2 and associated surface and injection facilities

Vertically bounded by storage seal

- Storage complex (purple): Storage site and surrounding geological domain, which can have an effect on overall storage integrity and security, i.e.

Vertically bounded by complex seal

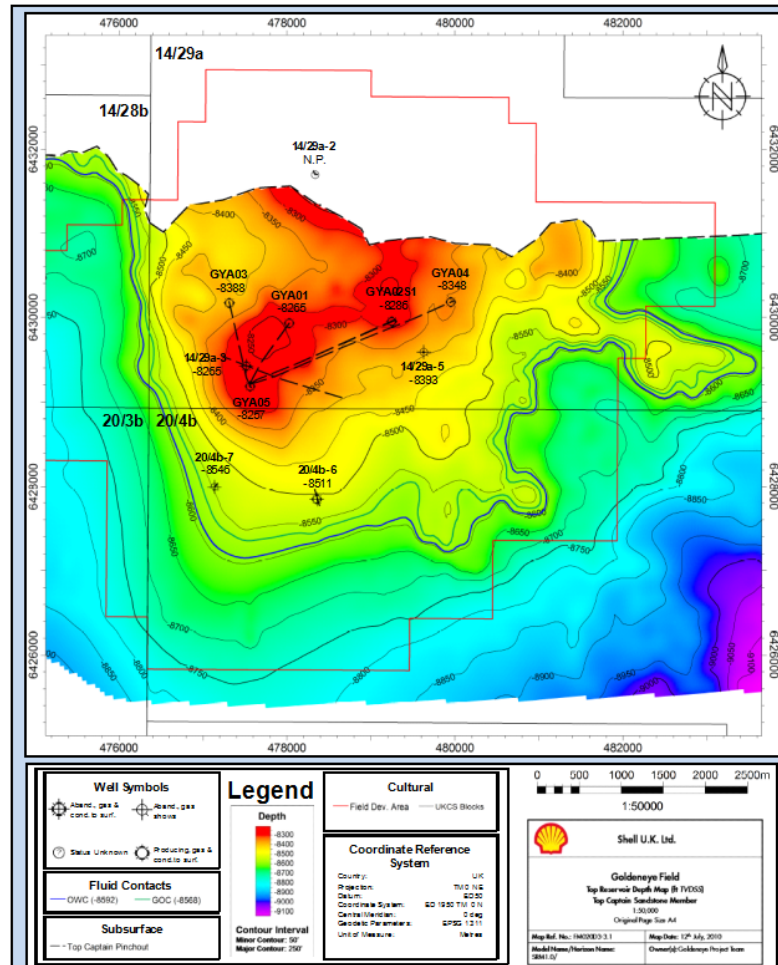
formations



GOLDENEYE STORAGE SITE & WELLS

- **Storage Site** – Includes the reservoir within the Captain Sandstone Member and rocks down to the base of the Cromer Knoll Group
- **Closure** – Structural dip closure is provided to the east, west and south with pinchout of the Captain reservoir sands to the north
- **Goldeneye Wells** – Of the five development wells, three are planned to be converted as injector wells, one will function as a monitoring well and one will be abandoned.
- **Abandoned Wells** – E&A have been assessed for the presence of effective barriers

- **Top Reservoir** – Depth Map showing the Goldeneye Storage Site, fluid contacts and wells.



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THE GOLDENEYE MEASUREMENT, MONITORING & VERIFICATION (MMV) PLAN

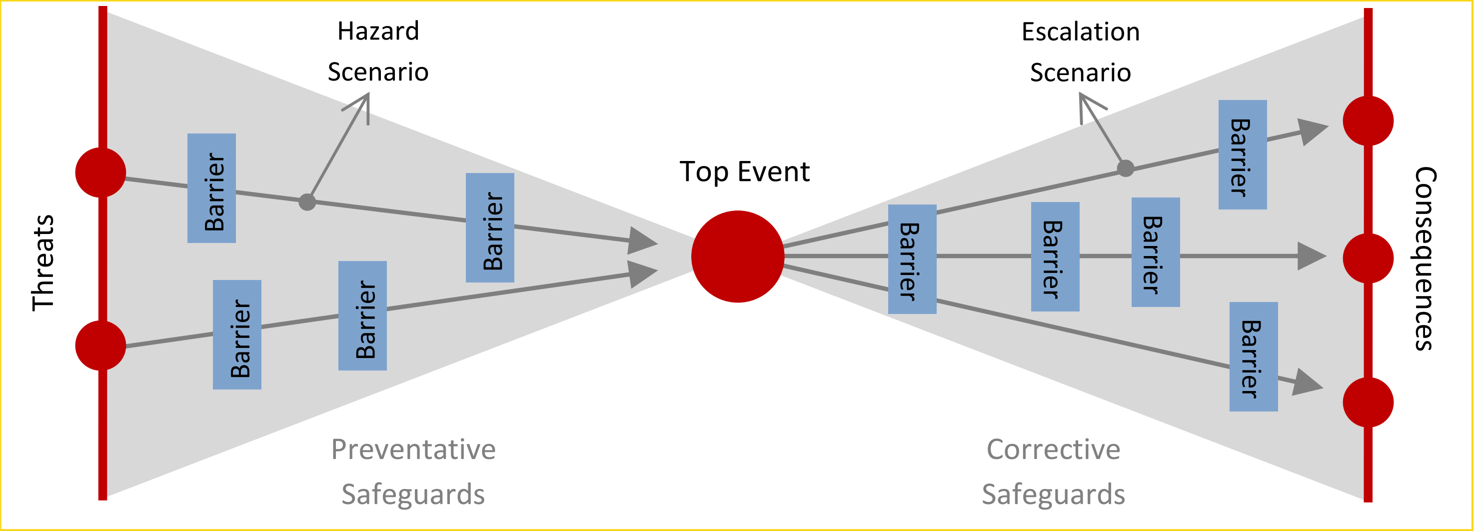
OBJECTIVES, RISK ASSESSMENT, BASE PLAN, CONTINGENCY PLAN & CORRECTIVE MEASURES

MMV PLAN OBJECTIVES

- ENSURE CONTAINMENT
  - demonstrate effective and secure CO_2 storage
  - containment risks affect project license to inject
- ENSURE CONFORMANCE
  - demonstrate actual storage performance is consistent with expectations about injectivity, capacity and CO_2 behavior inside the storage complex
  - provide support for transfer of liabilities
- VERIFY SAFEGUARDS
  - Verifying the expected effectiveness of existing safeguards created by site selection, site characterization and engineering designs
  - Creating additional safeguards using monitoring systems to provide

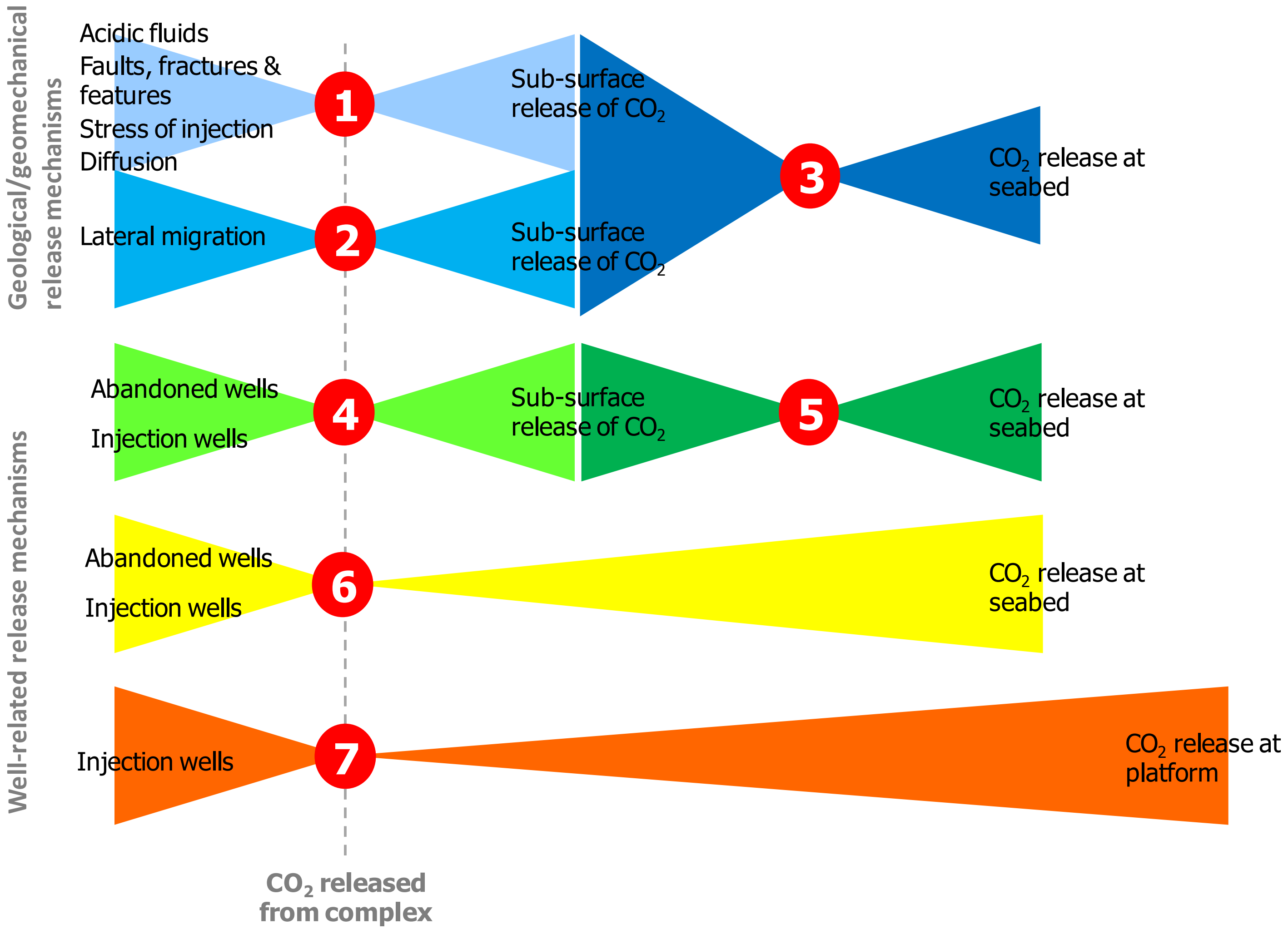
The Monitoring Plan covers all phases and domains of the CO_2 storage operation

BOWTIE METHOD – THEORY



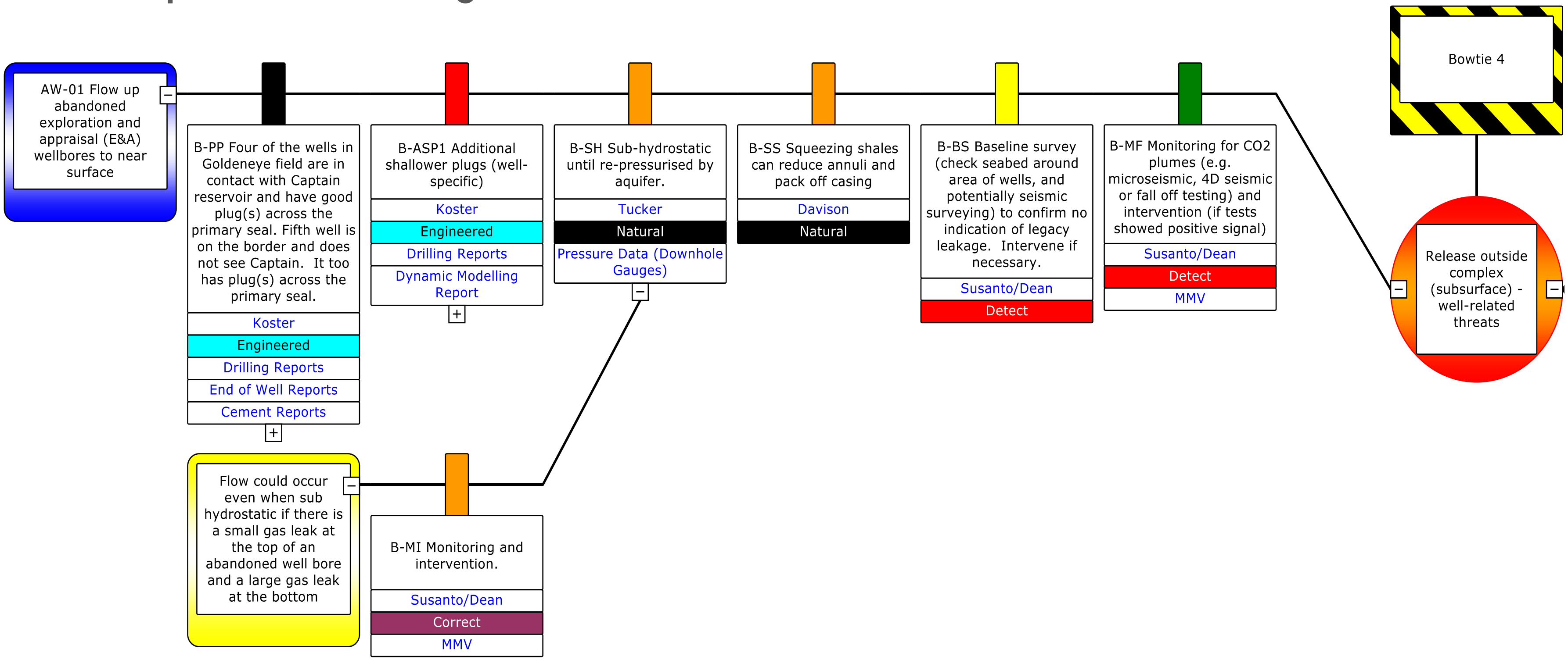
- **Top Event:** CO_2 leaving the storage complex
- **Threats:** mechanisms (migration paths) that lead to top event; identify potential leak paths
- **Consequences:** adverse effects to environment, people and reputation
- **Preventative Safeguards:** these decrease the likelihood of a threat leading to the top event
- **Corrective Safeguards:** these decrease the likelihood of significant consequences after top event

THE GOLDENEYE BOWTIE – MODEL STRUCTURE

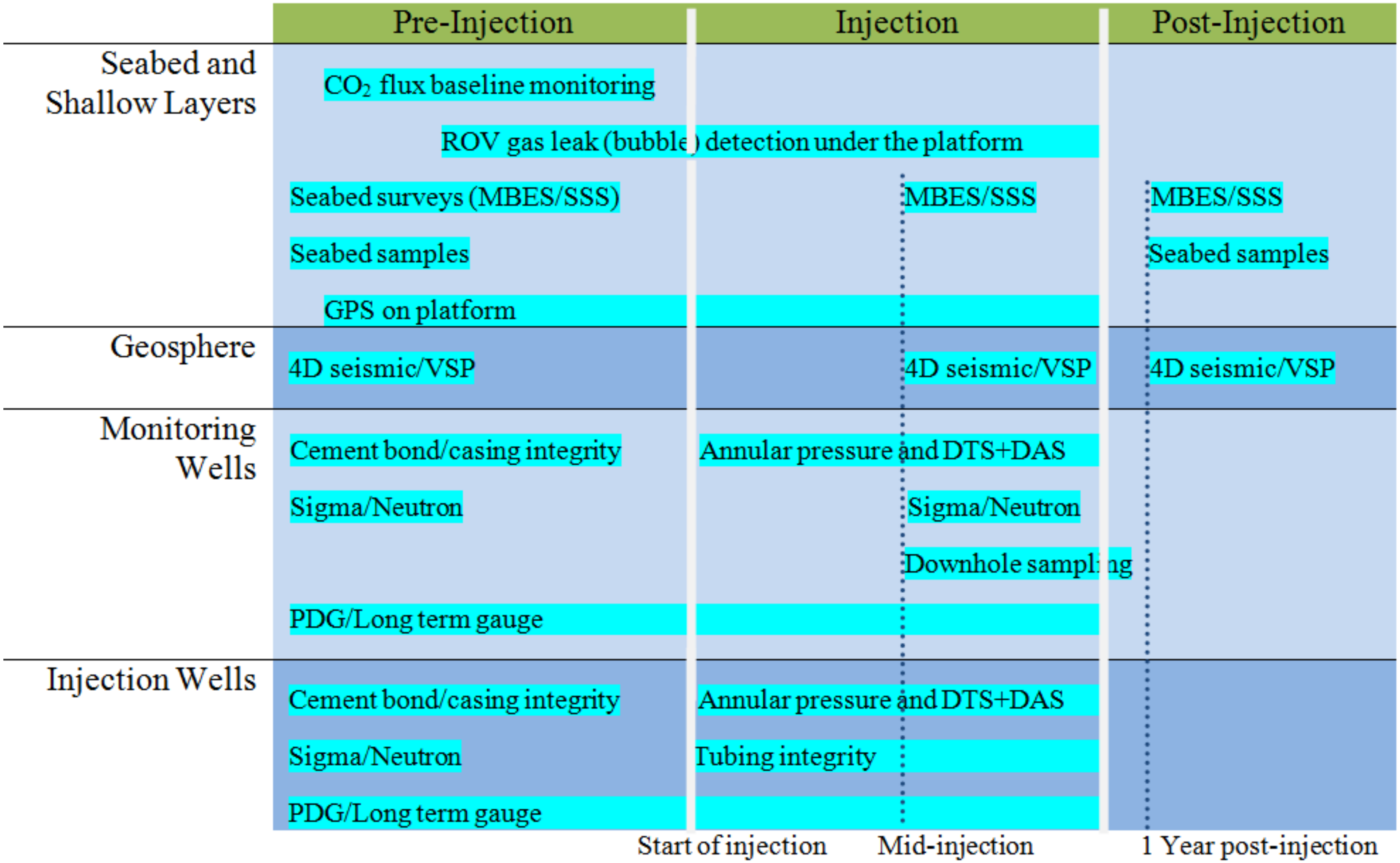


THE GOLDENEYE BOWTIE – EXAMPLE

- **Example Hazard and Barriers** – Extract from bowtie analysis illustrating preventive safeguards

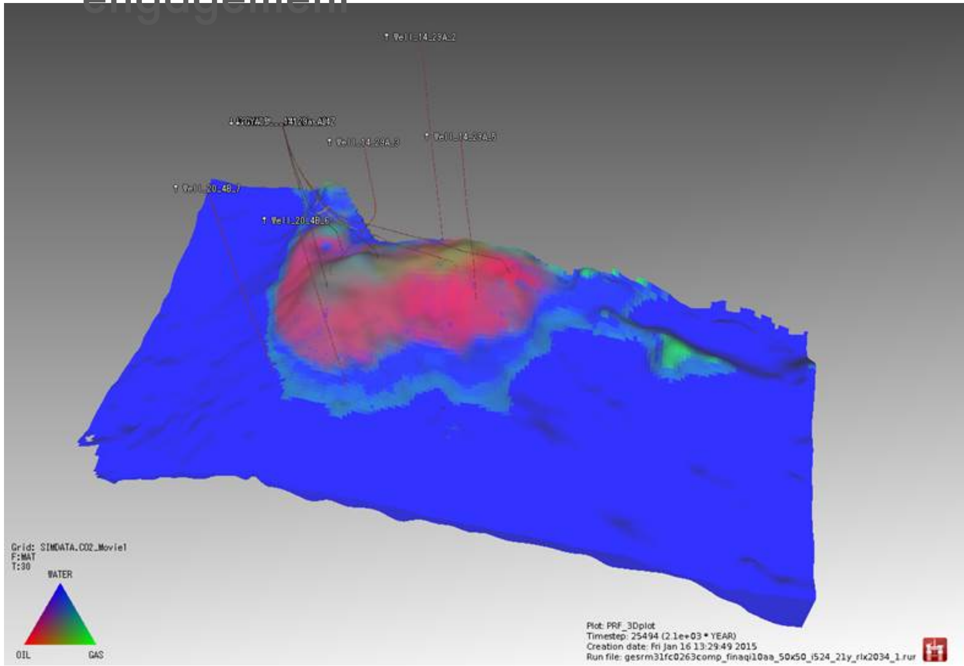


BASE CASE MONITORING PLAN



CONTINGENCY, CORRECTIVE MEASURES & POST CLOSURE PLANS

- **Contingency Plan**
  - Provides necessary information for corrective measures in case of suspected irregularities
- **Post Closure Plan**
  - Includes two post-injection seismic surveys: (~1 and ~6 years post injection) to confirm absence of any irregularities and conformance to dynamic models
  - First post-injection survey after store has seen highest injection pressures and plume has largest footprint
- **Corrective Measures Plan**
  - Informed and triggered by contingency monitoring, risk assessment, and regulatory engagement



Modelled distribution of CO_2 at the end of injection.

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FRONT END ENGINEERING DESIGN (FEED) PHASE & THE MMV PLAN

SUMMARY

FRONT END ENGINEERING DESIGN (FEED) PHASE AND THE MMV PLAN

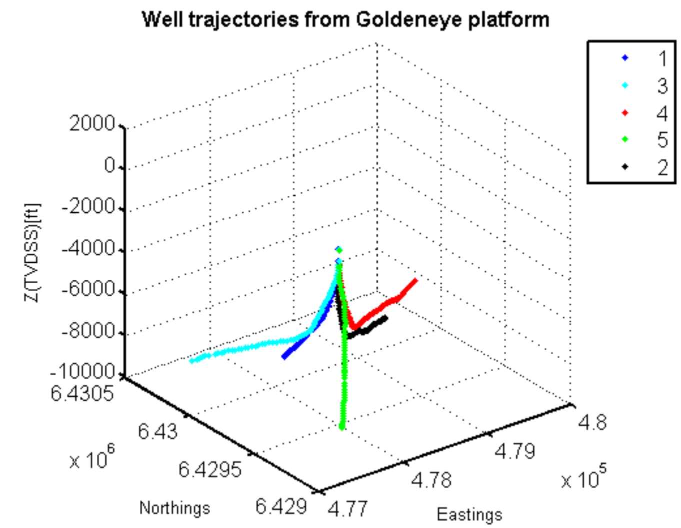
Besides technology feasibility assessments and cost/benefit analysis, during FEED, additional considerations require attention

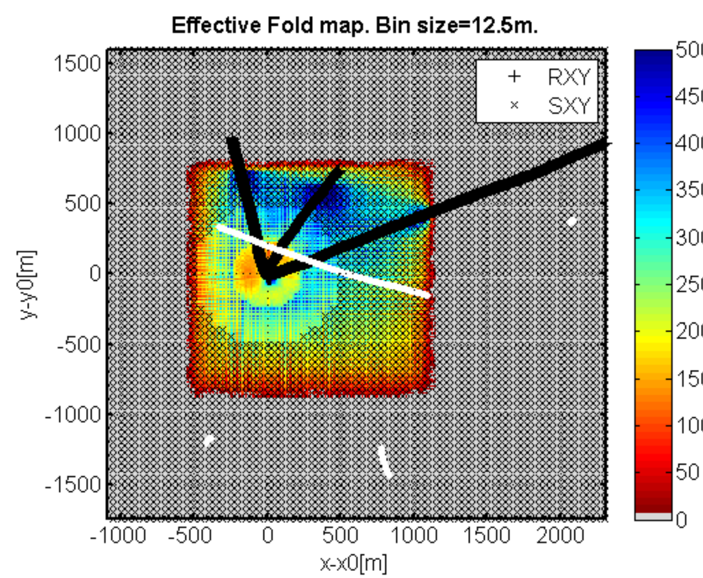
- Costs
  - 4D surface seismic is the preferred technology (balance frequency of repeats with high costs). Alternatives?
  - Need monitoring technologies that are operationally feasible and automated
- Operational constraints
  - Unmanned platform with limited space: rack space for Fiber Optics (FO) interrogator boxes, access to monitoring data
  - Power requirements on platform, battery life, biofouling, trawling activities
- Data management
  - Large volumes of data from FO monitoring (DAS, DAS VSP, DAS microseismic), bandwidth requirements and potential latency issues

FRONT END ENGINEERING DESIGN (FEED) PHASE AND IMPLICATIONS TO THE MMV PLAN

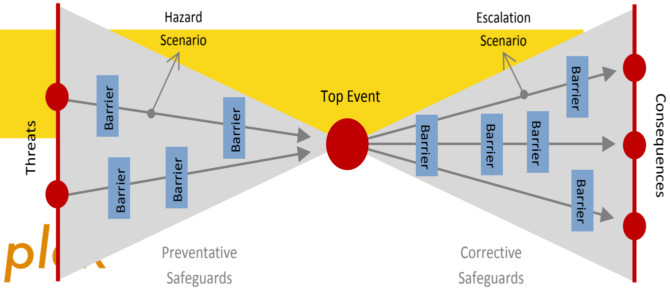
Emerging technologies offer potential low-cost containment monitoring solutions

- Opportunities
  - Multi-well DAS VSP can provide high fold image of ~2km2 around wells at reservoir level and ~0.5Km² at the level of secondary storage
  - Should CO_2 leak vertically out of Captain, a 4D DAS VSP is expected to resolve 4D anomalies as the CO_2 enters secondary storage
  - Ability to monitor if CO_2 leaks out of abandoned wells in image area
  - Early deployment: requires field trial





SUMMARY



Monitoring for the Goldeneye Storage Complex

- *Risk-based* MMV plan according to identified and assessed threats using the Bowtie Method (key technology: 4D seismic)
- *Regulatory compliant* covering all phases and domains of CO_2 storage operation to demonstrate the absence of any irregularities and conformance
- *Diversified monitoring technologies complement* each other in space and time to reduce uncertainties and reduce risks to acceptable levels
- *Contingency and Corrective Measures* to identify the source/cause of any irregularities, assess likely evolution and then plan remediation in consultation with the regulatory authorities
- *Post Closure Plan* in support of handover to confirm absence of any irregularities and conformance to dynamic models
- *FEED Phase Challenges* on MMV plan such as operational constraints, costs, data management, etc.