geostock

The international key player in underground storage

Natural Gas UGS in Salt Caverns

Integrity Management and Performance Optimization

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together @ VINCI

ENTREPOSE

Why CIMS?
Safety, Efficiency & Sustainability

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Assess Integrity of Salt Caverns under operating conditions

Stability / Closure

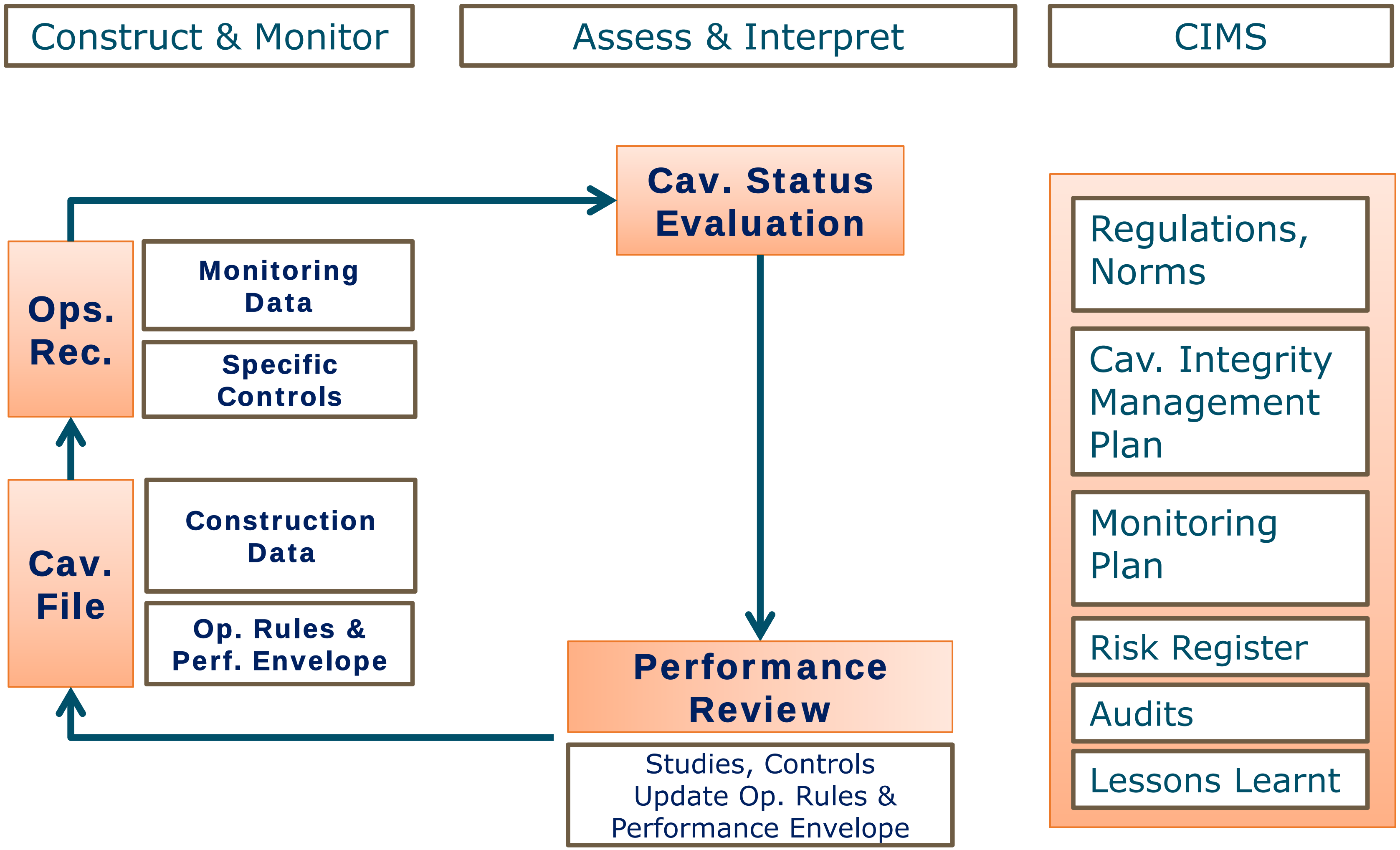
Tightness

Optimise Caverns operating performance and lifetime

- **Develop a Pragmatic** methodology **adapted** to the specificity of **U**nderground Natural **G**as **S**torage (UGS) caverns
- **Organize and maintain a Cavern File** for lifecycle analysis.
- **Define and organize Monitoring & Controls**
- **Review periodically the Cavern Operating Envelope** and **evaluate its Remaining Lifetime** (Creep/Fatigue).

Note : CIMS focuses on caverns only. Full Asset integrity management includes the wells and the Well Integrity Management System (WIMS).

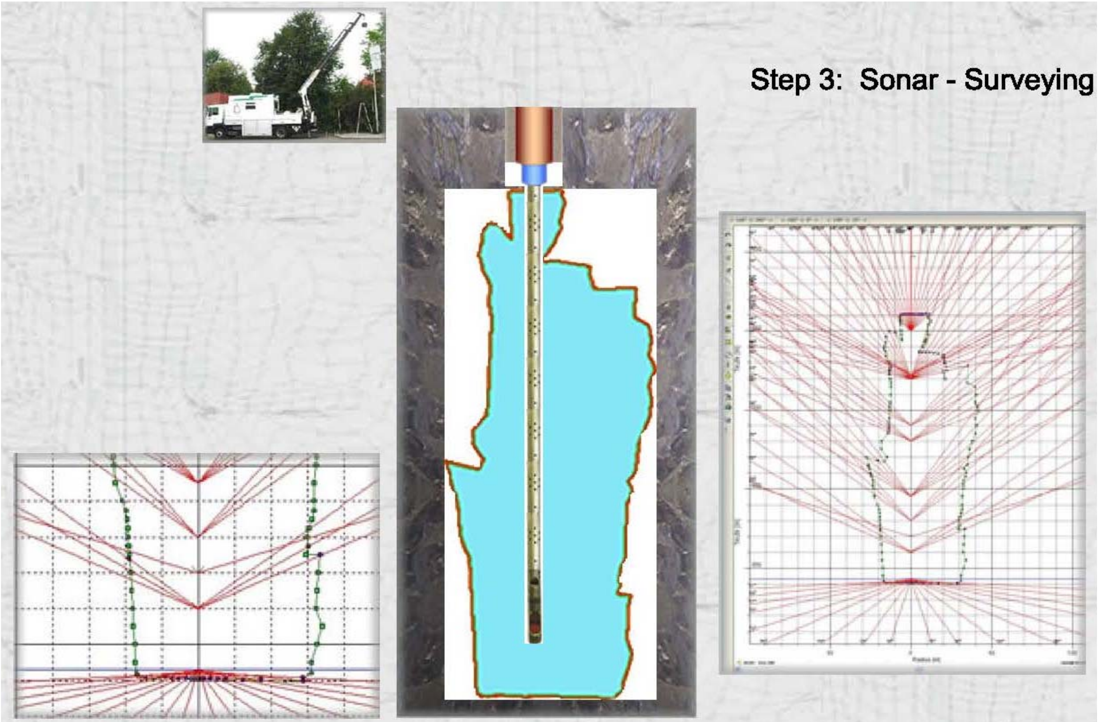
Cavern Integrity Management Sys.
Typical Workflow

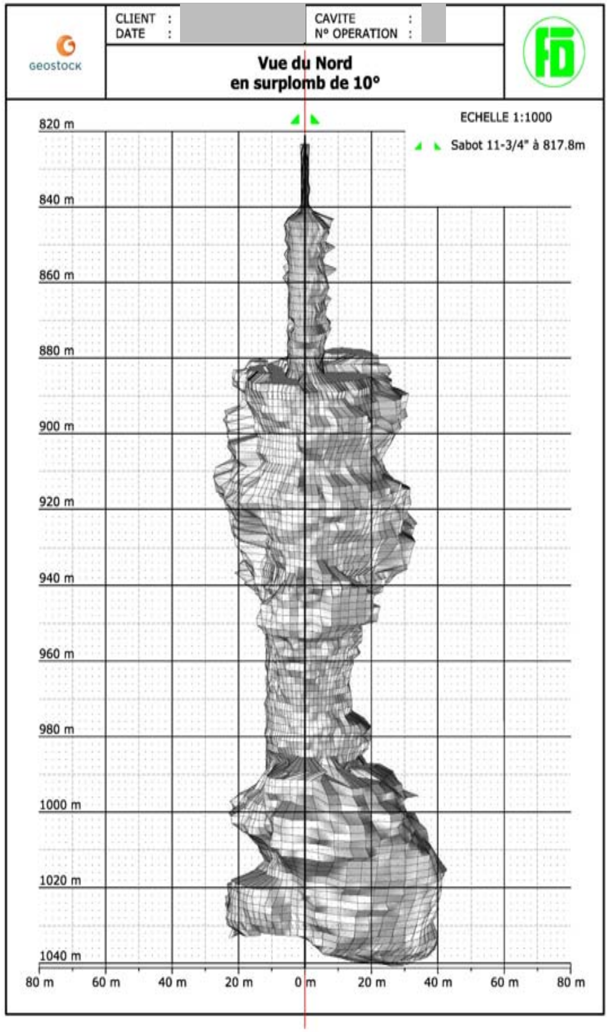


Cavern File
Construction Data

- **Create & Maintain cavern file**
  - Geology
  - Design
    - Geotechnical
    - Leaching
  - Construction Records
  - Tests Reports
  - First Gas Filling Report (Reference for original cavern free volume from de-brining and first sonar under gas)
  - First Sonar under gas and subsequent controls

Echometric (SONAR) Surveys





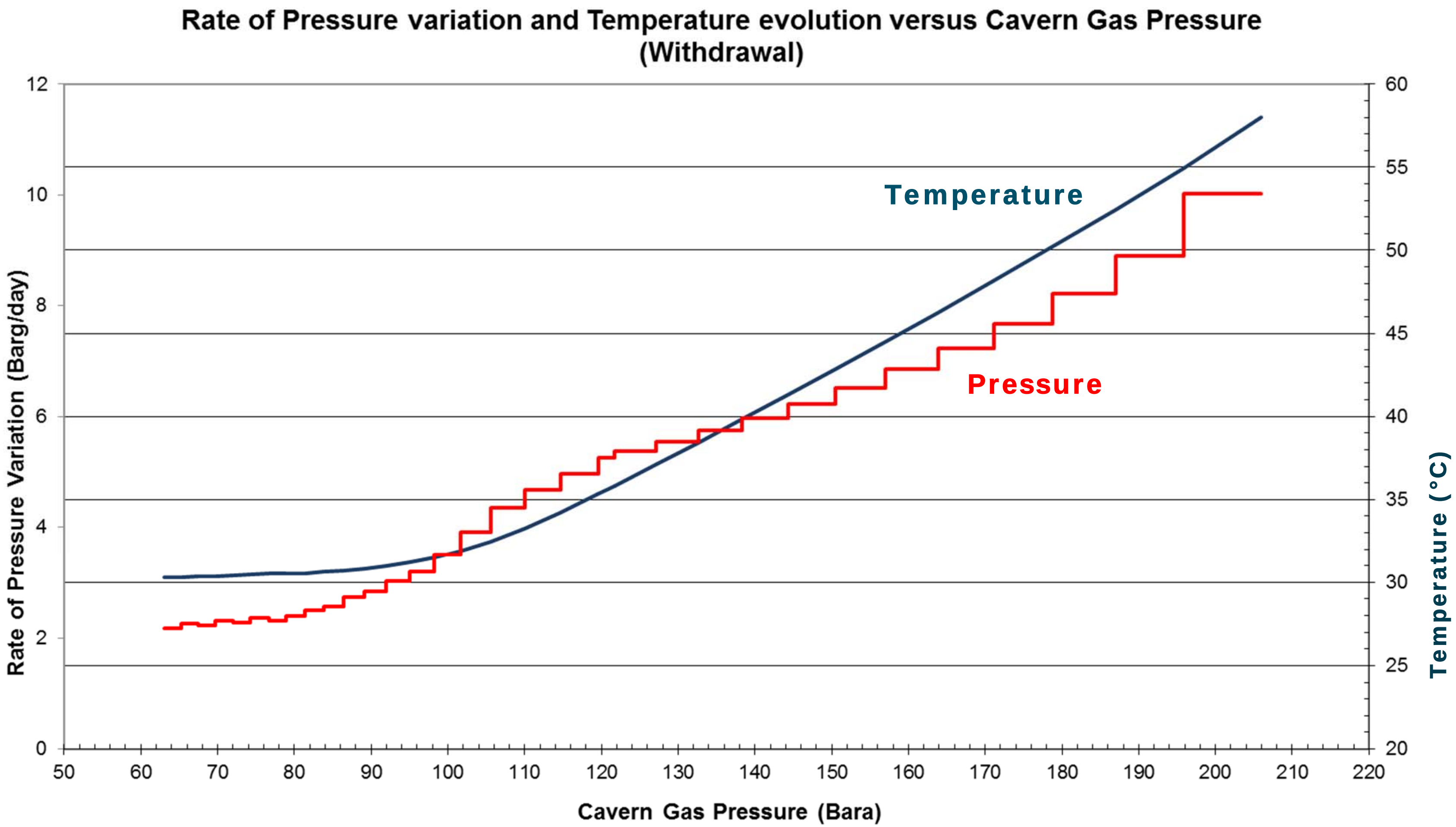
Cavern File

Operating rules and performance envelope.

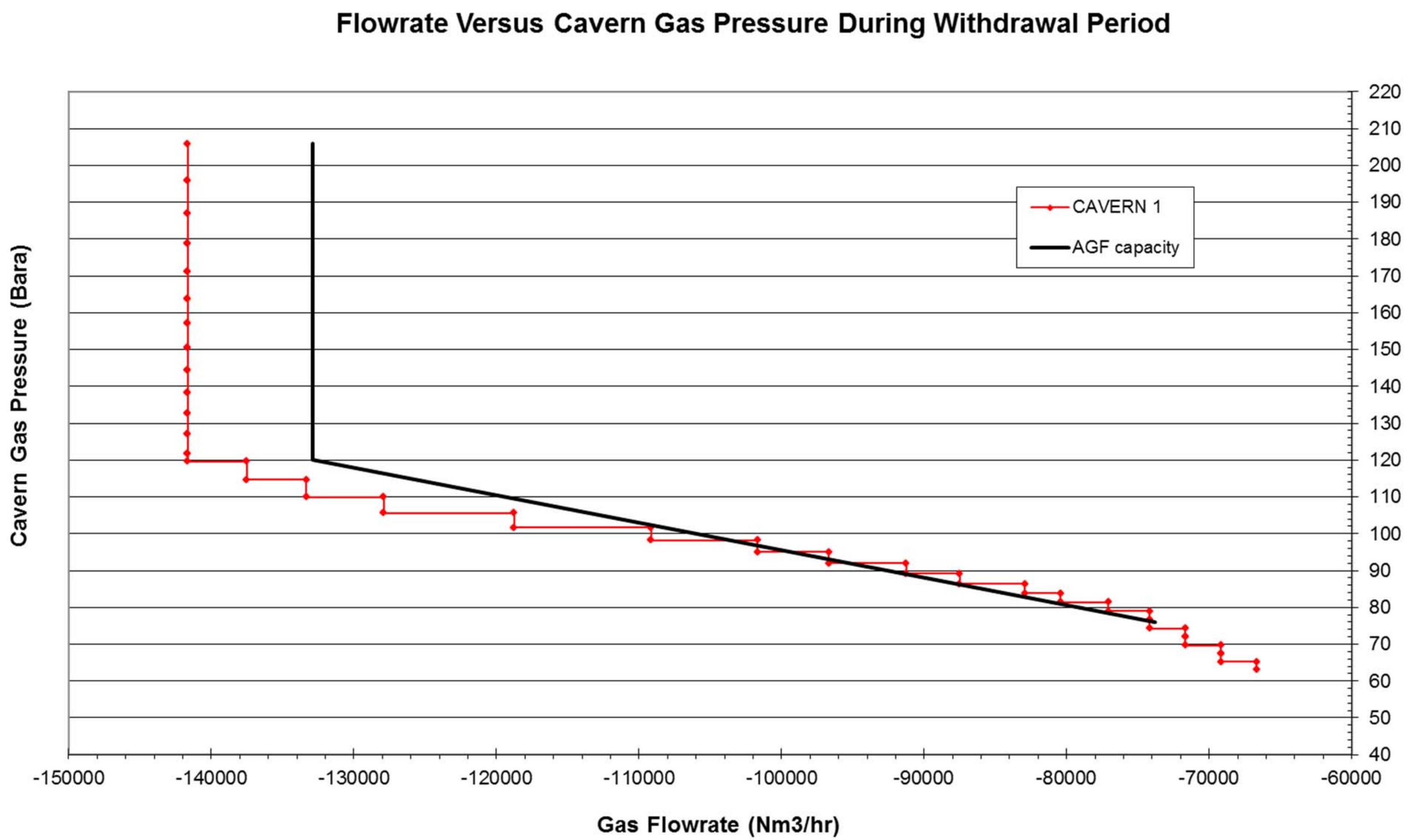
- **Specify, Challenge, Update :**
  - Pmin, Pmax, Tmin, Tmax
  - Maximum allowable duration at minimum pressure
  - Qmax
  - Caverns performance curves
    Evolution of maximum deliverability/injectivity vs time and/or inventory; of maximum pressure change per time unit vs P and/or inventory; etc.
  - Inventory, Working Gas and Cushion Gas relationship

Note: Particulars may include Solution Mining under Gas (SMUG), ''Soaking'' or pressure support via brine compensation.

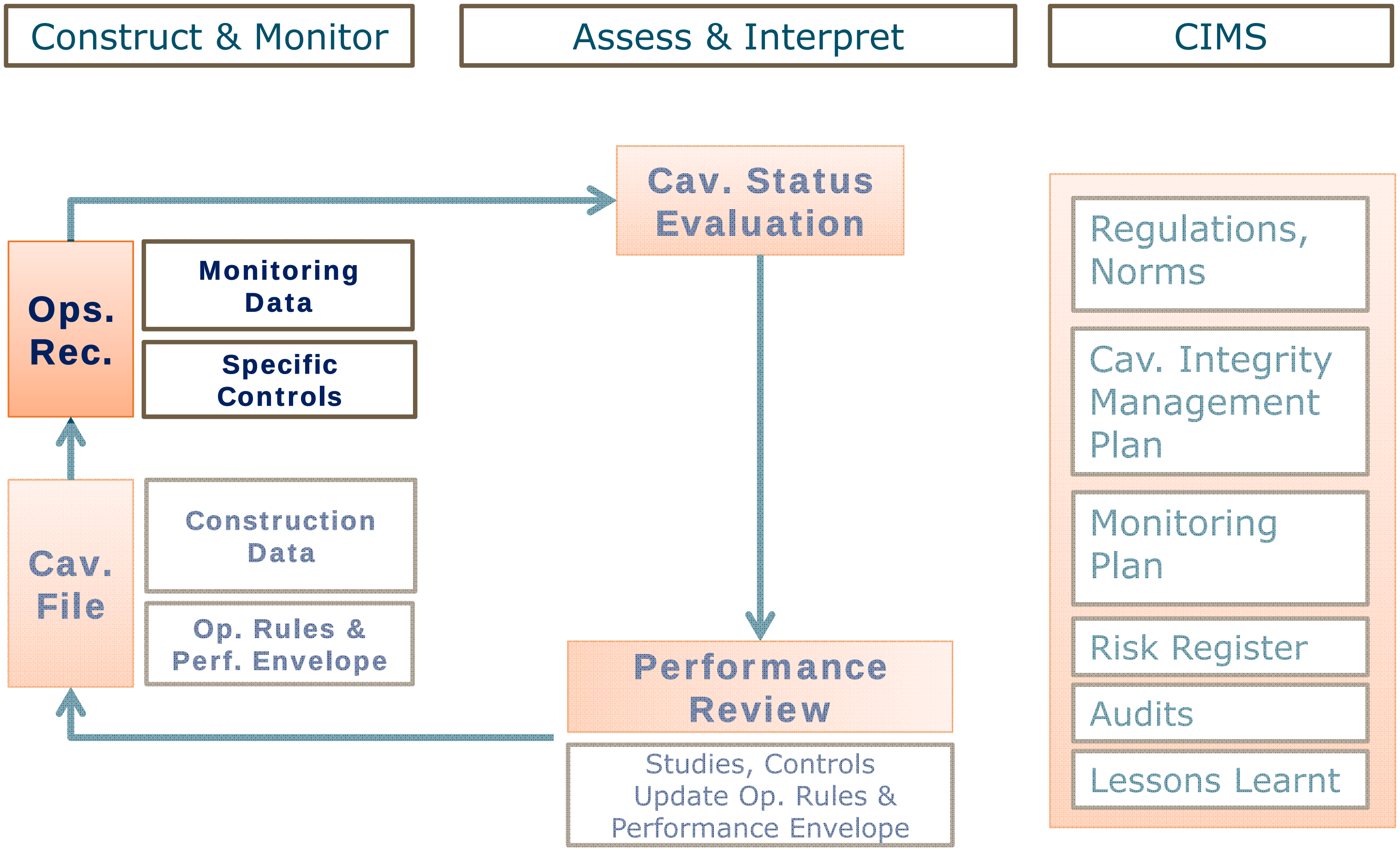
Evolution of maximum allowable rate of pressure decrease and of temperature vs. cavern pressure



Flowrate and pressure relationship



Cavern Integrity Management Sys.
Typical Workflow



Operation Records

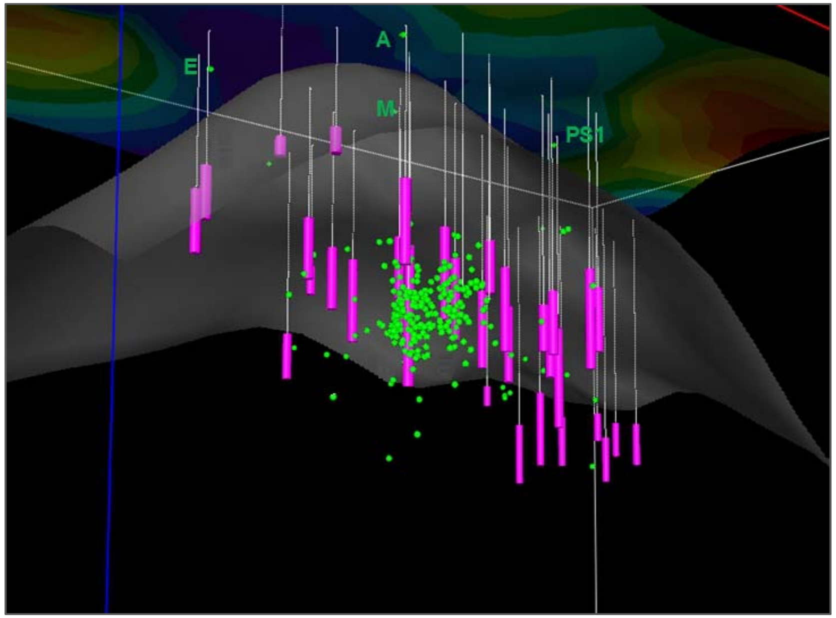
- **Collect and organize Monitoring data**
  - WHP, WHT, flow rate, cumulative volume in/out, inventory, gas quality, fluids sampling, etc… to be typically gathered by the operator.
  - Microseismic monitoring

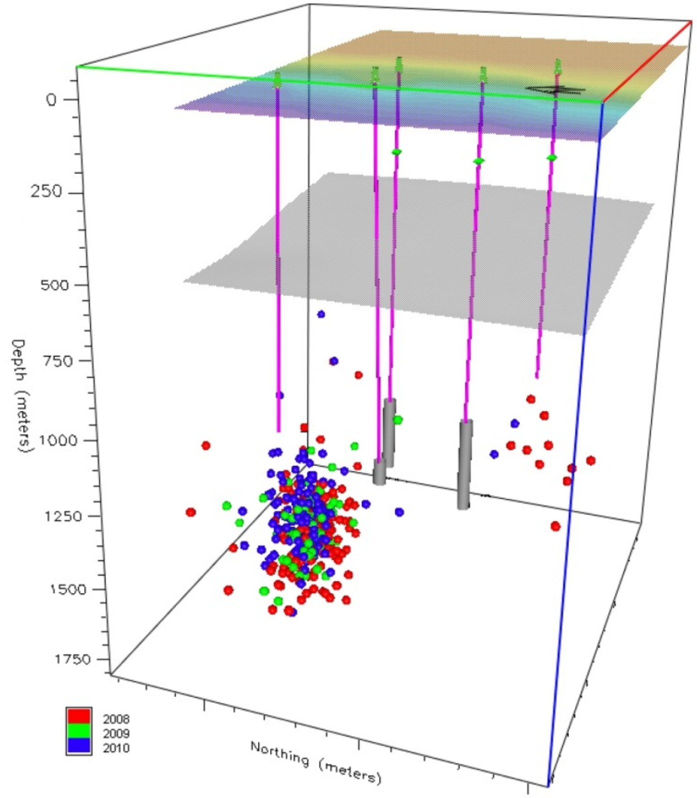
- **Specific Controls: Design, Procure, Supervise, Evaluate**
  - Logs (Pressure Temperature, Moisture)
  - Bottom tag
  - Neck & roof controls
  - CCL (hanging string)
  - Sonars under gas
  - Re-Certification, cavern re-testing as required
  - Subsidence Monitoring

Seismic Monitoring – Seismic sensors

Seismic Monitoring – Seismic recorder

Seismic Monitoring
Analysis & interpretation

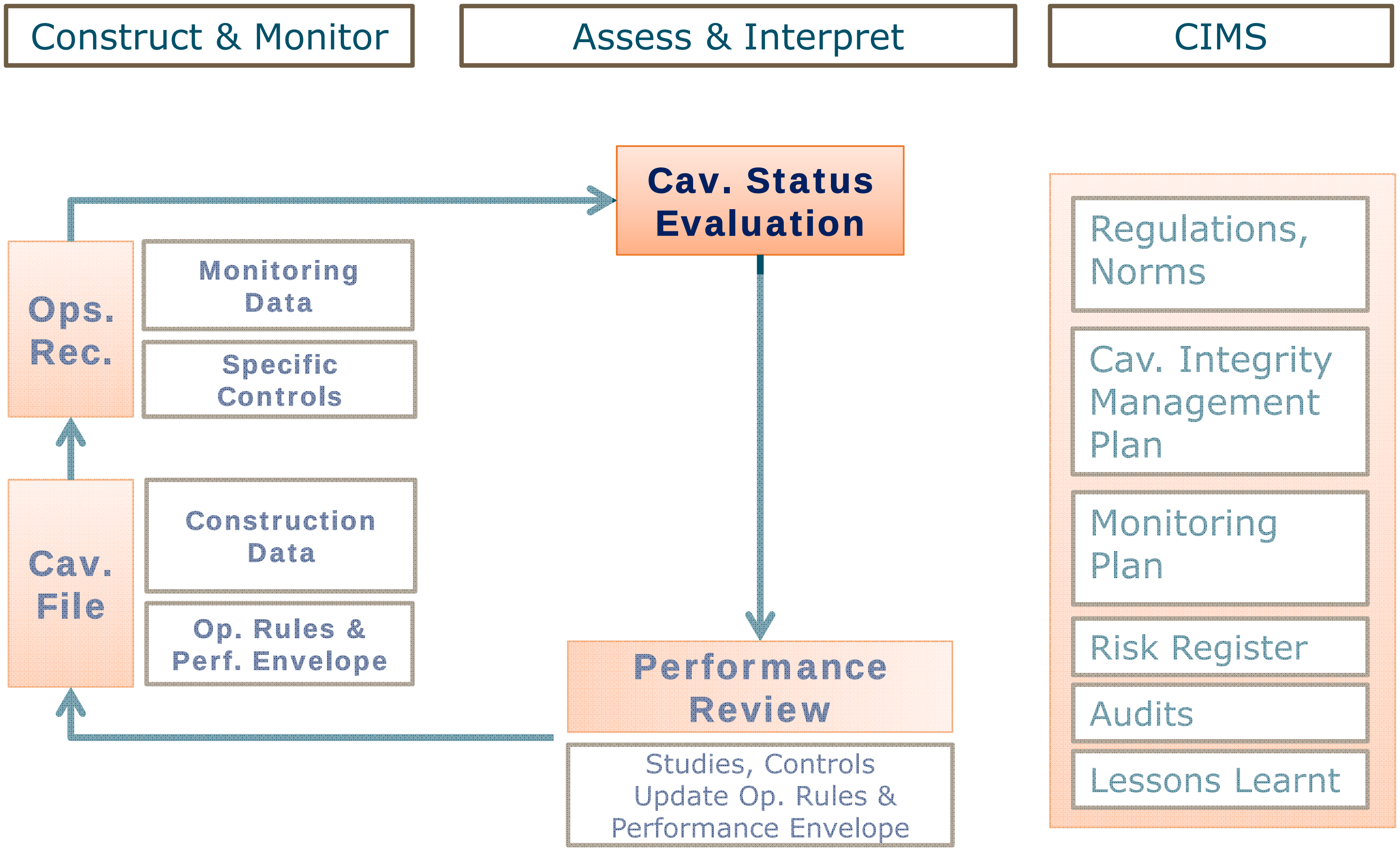




3D seismic event location

- *Caverns roof*
- *Insoluble block falls*
- *Pillars instability*
- *Gas tightness*
- *Micro-seismic events related to geological structures*

Cavern Integrity Management Sys.
Typical Workflow

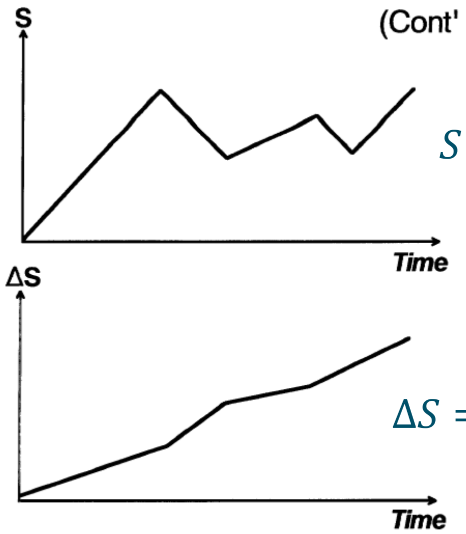


Cavern Status Evaluation (1/3)

- **Assess Inventory based on Material Balance and Thermodynamical model**
  - Collect the operating data per cavern, Sonars and Pressure/Temperature log data. Perform QA/QC on input data. Validate data against operating rules. Organise the data file.
  - Construct, Calibrate, and Match Thermodynamical Cavern Model (typically with 1 year of production data + leaching & first filling data). Main adjustment parameters are cavern geometry (volume, surface), thermal parameters, modeling of the leaching period)
  - Assess inventory by running model. Main adjustment parameter is metering errors.
  - Produce periodical Cavern performance and inventory review and assessment report.

Thermodynamic Model

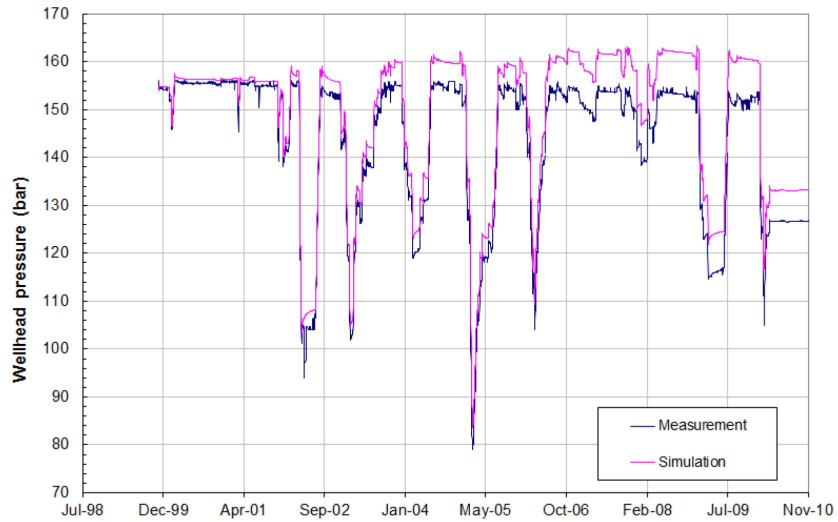
Error on the inventory increases with time

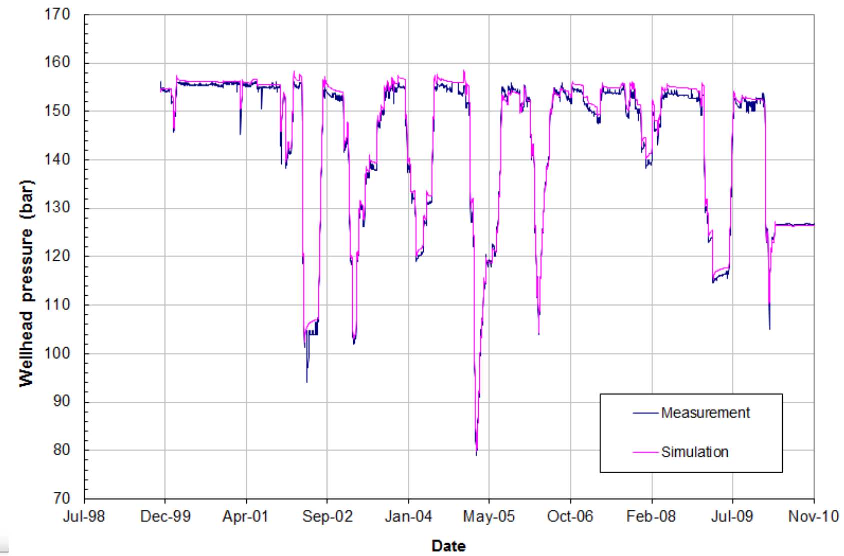


$S = \Sigma\, Q$

$\Delta S = \Sigma\, |\Delta Q|$

Without movement correction





Cavern Status Evaluation (2 / 3)

Model Benefits: Monitoring and prediction

- Third party QA QC
- Inventory check.
- Assessment of operating conditions (in particular compliance with operating envelope)
- Early detection of equipment malfunction
- Recommendations for Improved monitoring
- Prediction for next operating periods, Programs and Performance update (working gas, flowrates, hydrate formation risk, etc)
- Simulation of optimized operating strategies (performance, energy savings): caverns operated in parallel, in pools, etc…

Note: on-line thermodynamical model may contribute to real time optimization of caverns operation (e.g. assessment of nominations)

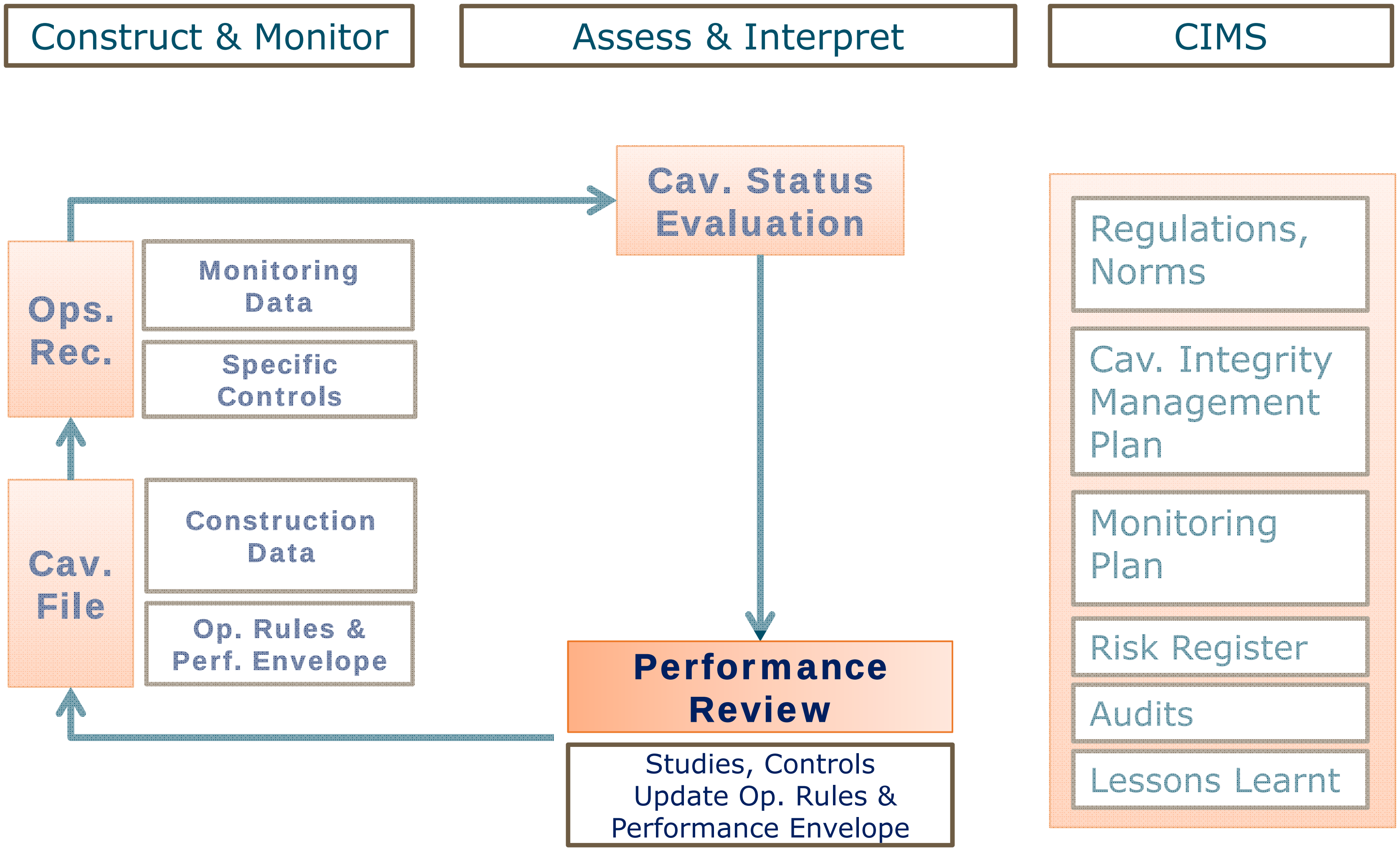
Cavern Status Evaluation (3 / 3)

- **Review and Assess Cavern stability (typically on a yearly basis or in case of anomaly detection). Main parameters: Stability and Closure.**

- **Input data:**
  - Pressure and temperature evolution within the cavern
  - Sonars in gas
  - Bottom cavity tags
  - Microseismic monitoring
  - Subsidence monitoring

- **Output data: Cavern stability review and assessment report including:**
  - Caverns Stability assessment under the operating conditions implemented (incl. evolution of cavern geometry in case of SMUG or soaking)
  - Evaluation of closure and anticipated evolution
  - Evaluation of Subsidence and anticipated evolution
  - Recommendations for optimisation of operating envelope (upgrade or downgrade and recommendations for remedial actions in case cavern damage is identified)

Cavern Integrity Management Sys.
Typical Workflow



Performance Review (1/3)

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Benefits: Design Update, Optimizing Working Gas Capacity and Operating Envelope, de-bottlenecking.

- **Efficient communication between Engineer, Operator, Owner is key to success**

- **Based on monitoring feedback** (monitoring data, gas quality, closure…) **and on specific studies:**

  - Check whether in/out flow performance curves (vs Pressure or inventory) can be improved (based on heat transfer assessment from operating data)

  - Update the cavern specific performance curves, typically:
    - Decrease the minimum pressure limits (Pmin; Pmin min) and increase the maximum allowable duration at minimum pressure
    - Potentially increase Pmax
    - Check feasibility of new operation scenarios

  - Update & optimise operating rules and support permitting process required for their implementation

Performance Review (2/3)

- **Main factors constraining the caverns performance envelope:**

  - Long term stability & tightness: Coupled Thermodynamical-Geomechanical parameters.

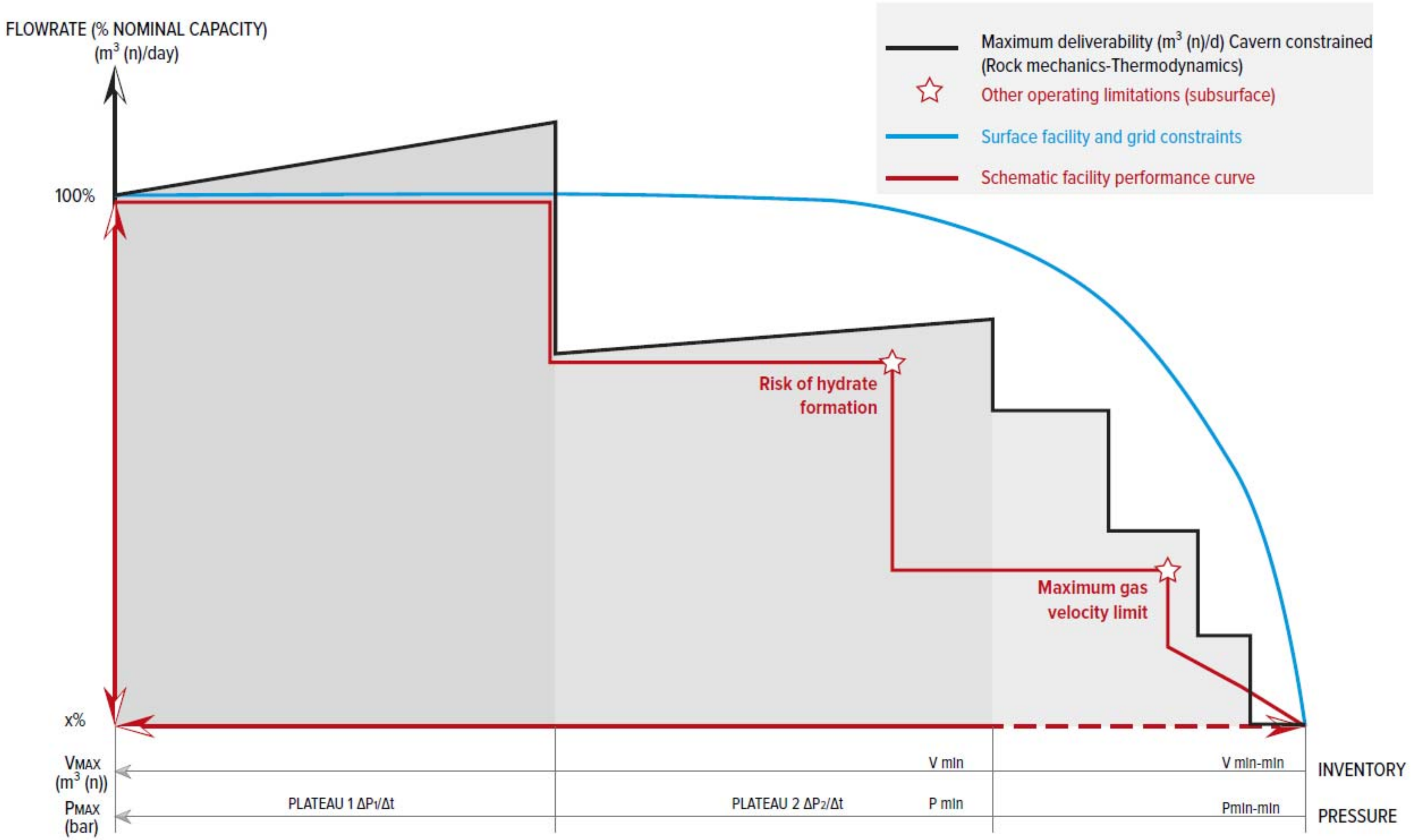
    Some specific modelling may be required in case of bedded salt (stress accumulation as a result of differential creep and fatigue effects) or if stability due to neighboring cavern is at stake.

  - Hydrate formation: Thermodynamical evolution

  - Positive temperature at wellhead: Thermodynamical evolution

  - Erosional Velocity limit in production tubing: maximum allowable flow rate for given Pressure and Temperature in cavern

Typical Cavern performance envelope:
Evolution of key operating parameters and constraints during withdrawal

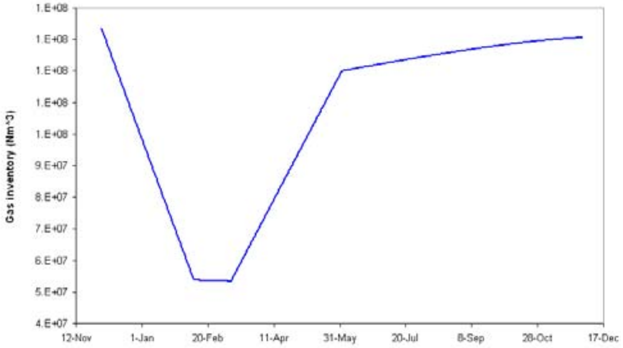


Performance Review (3/3)

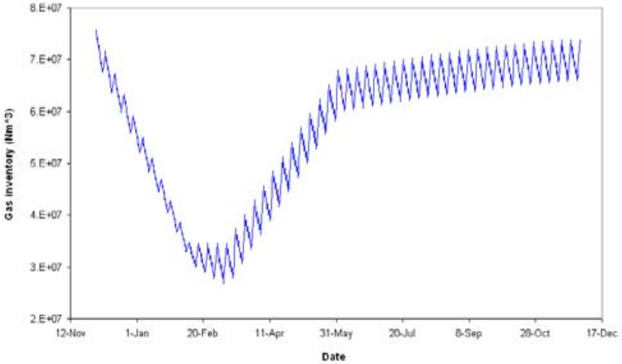
- **Workflow:**
  - Collect thermodynamical data & calibrate thermodynamical model.
  - Build typical representative operation scenarios (communication with stakeholders is crucial)
  - Create a coupled Thermo-Geomechanical model.
    Typical workflow includes:
    - Create a 2D (Abaqus) finite element model of the caverns. Qm review.
    - 2D Performance Review for one cavern. Pmin review.
    - 2D Performance Review for all caverns. Time vs Pressure Range.
    - Create a 3D (Abaqus) finite element model as required for particular cases (cavern shape irregularities, Low Temperature, irregular cavern field, etc…).

Performance Review
Typical operation scenarios

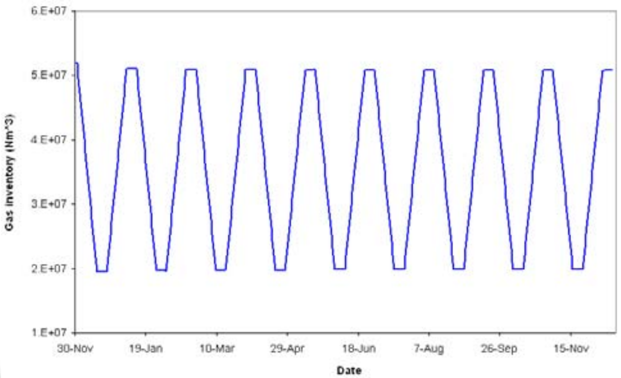
- **1- Purely seasonal cycling**



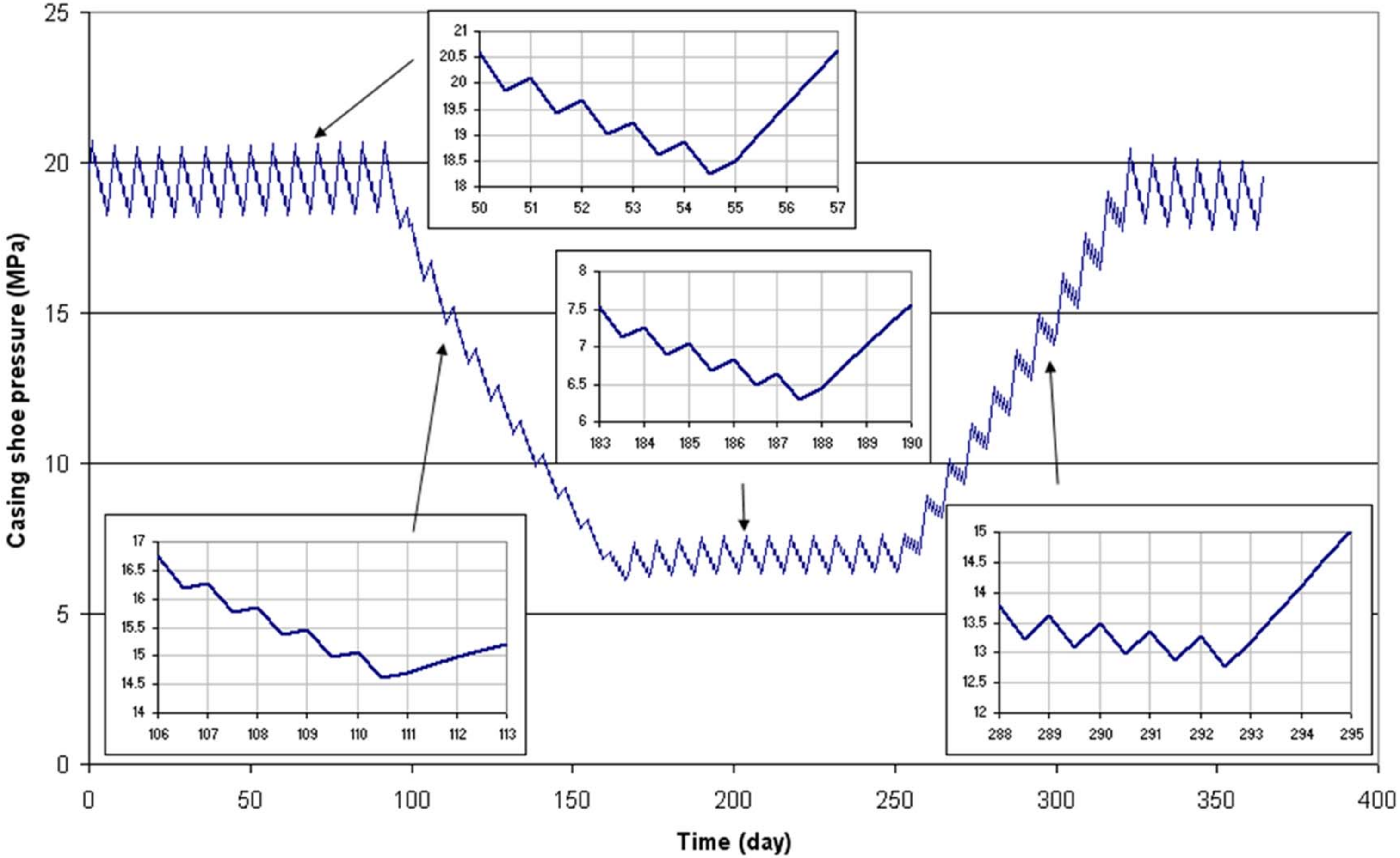
- **2- Seasonal micro-cycling**



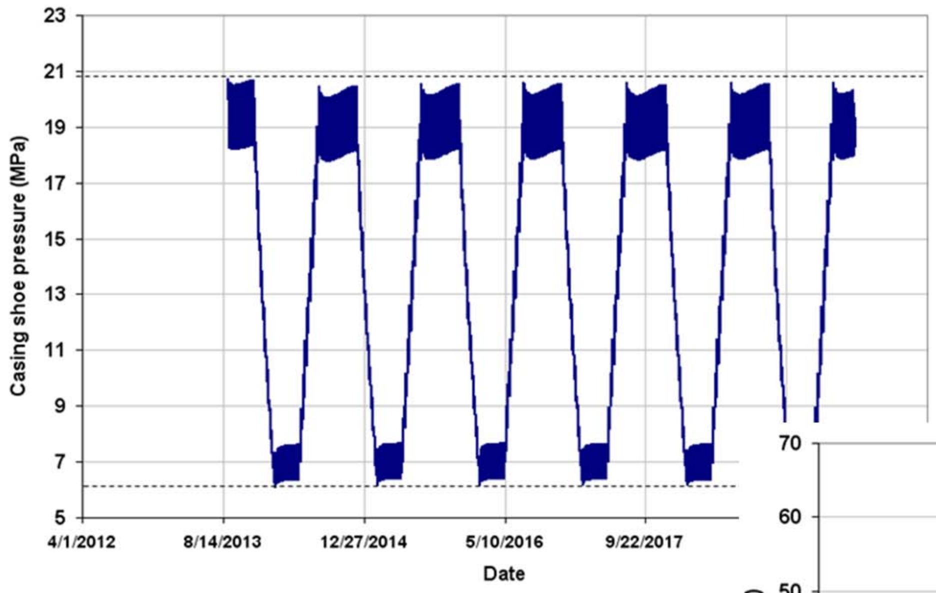
- **3- Multiple macro-cycling**

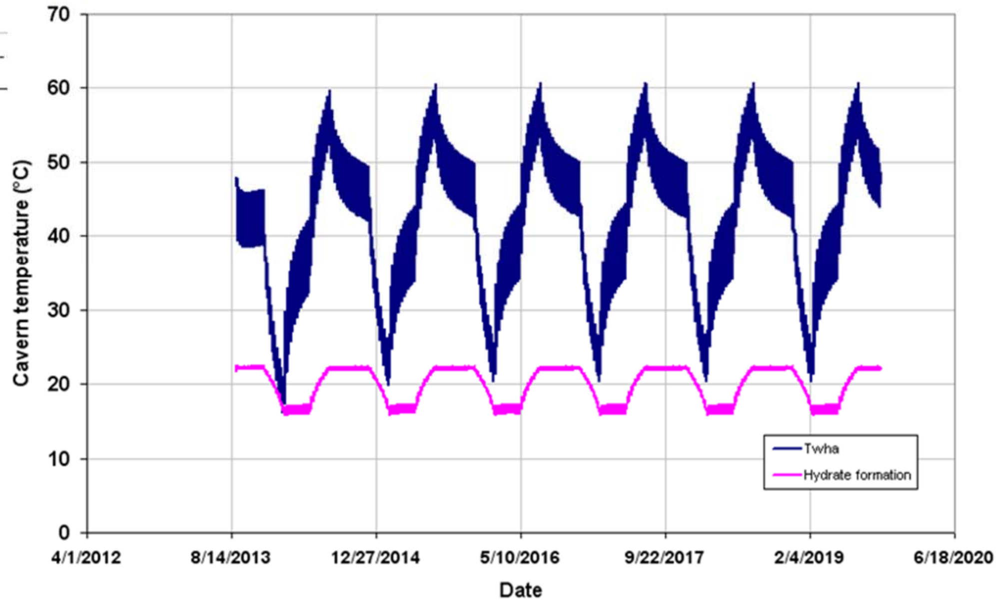


Performance Review
Building an operation scenario
(based on pressure cycles)

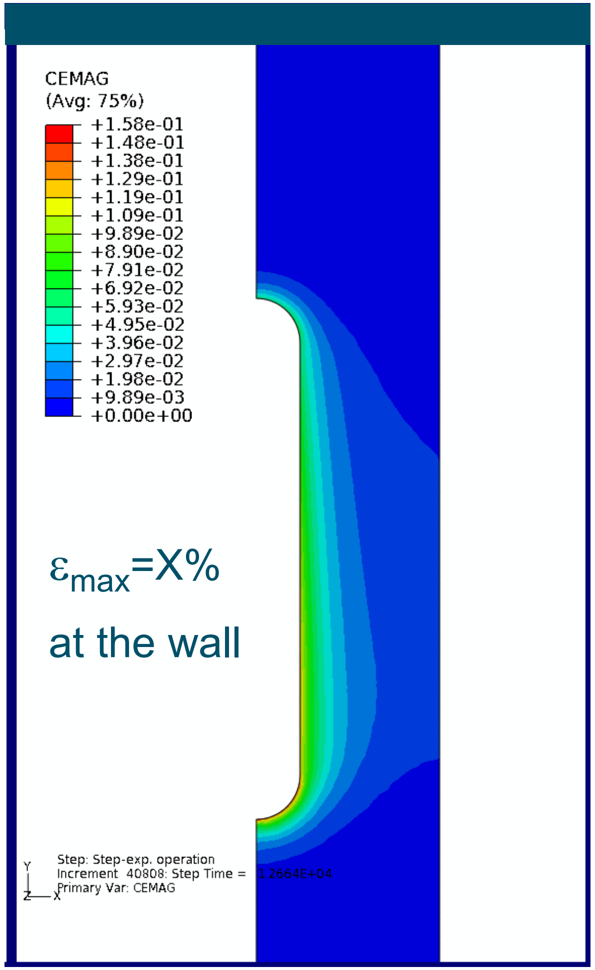


Performance Review
Evaluating temperature and hydrate formation limit



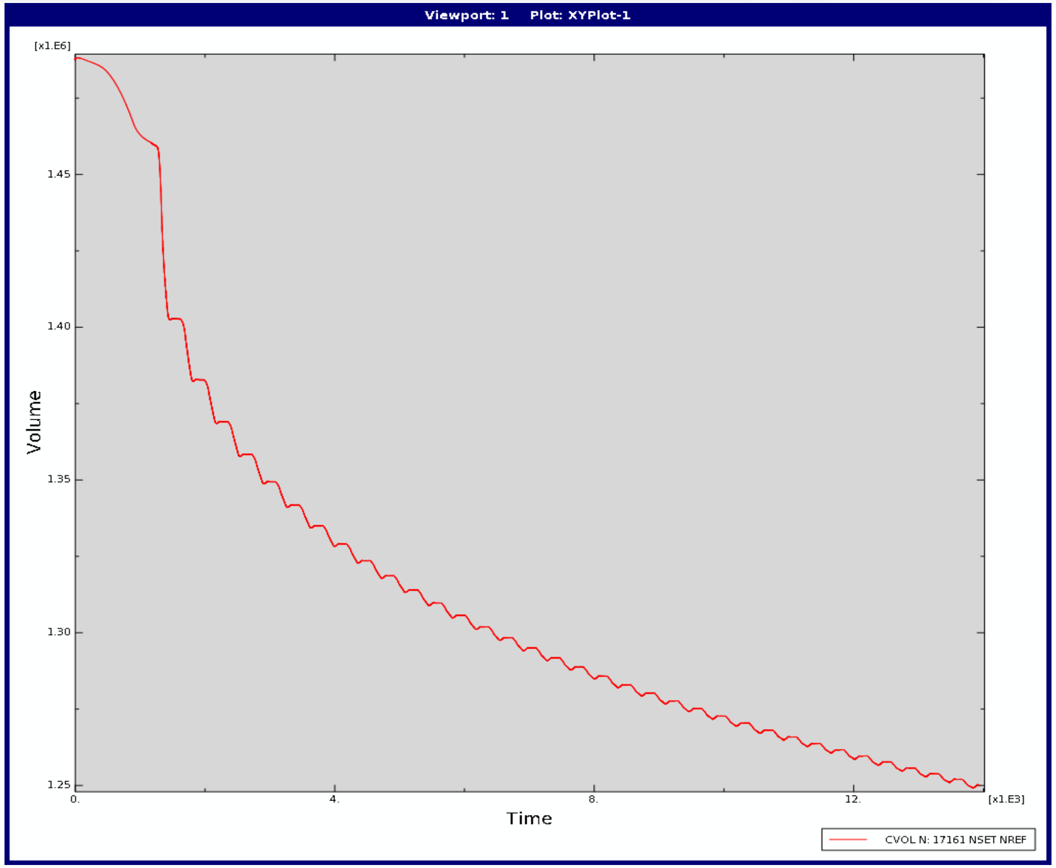


Performance Review
Prediction of closure evolution



ε_{max}=X%

at the wall



Volume loss: ε_v=Y%

Performance Review
Stability evaluation

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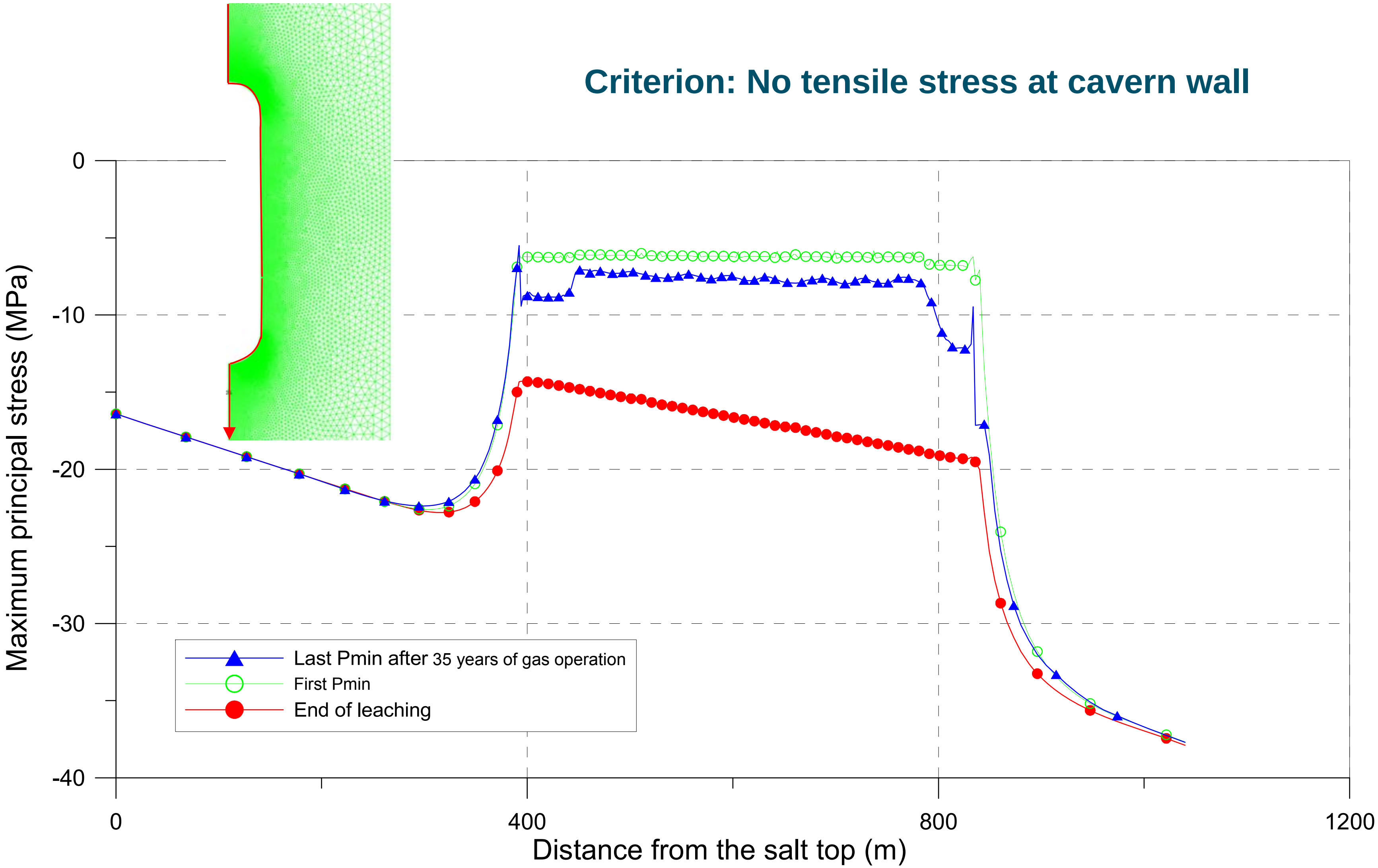
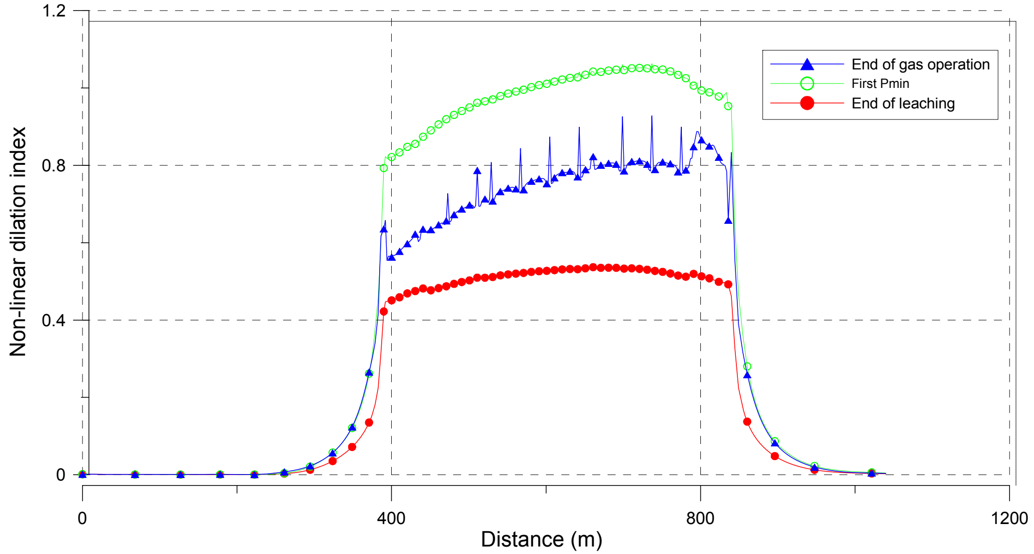
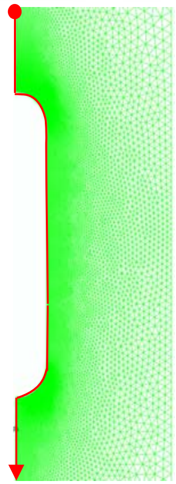


ENTREPOSE

Cavern performance analysis: Evaluation of dilation index

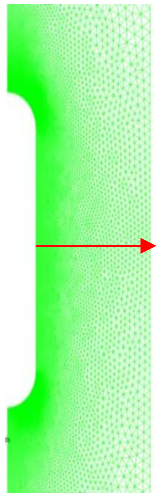


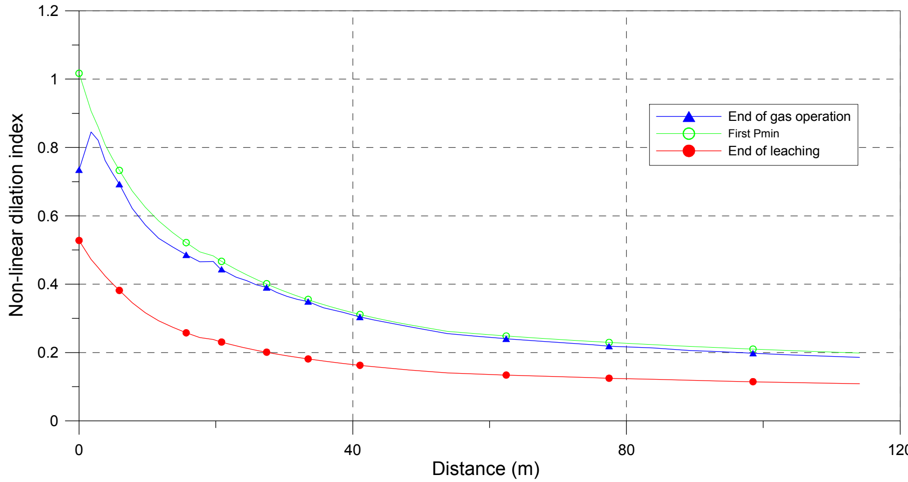


η_{max}=1.12

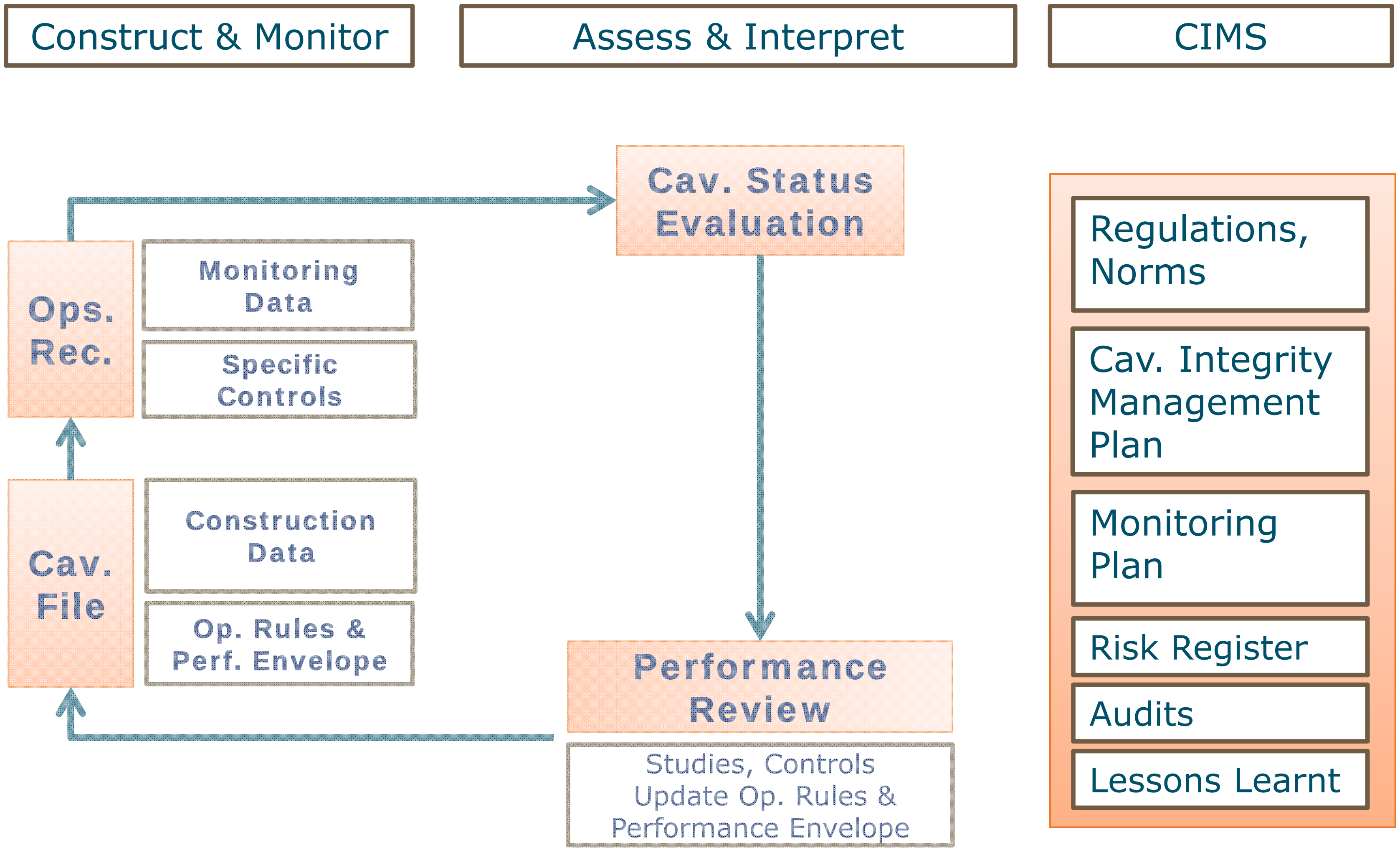
Criterion: η < or close to 1

η_{max}=1.02





Cavern Integrity Management Sys.
Typical Workflow



Cavern Integrity Management System

- **Regulatory Requirements.**
  - Reference documentation (Documentation watch).
  - Bridging document (Clarify local regulations against professional associations such as SMRI and company rules).
- **Caverns Operating Rules and Performance Envelope.**
- **CIMS Management Plan.**
  - Describe and adapt the cavern integrity process work flow to the client.
  - Describe roles and responsibilities (RACI chart, Job Descriptions)
- **Cavern Monitoring Plan.**
  - Operation parameters data base
  - Requirement for sonar, subsidence, micro-seismic, temperature logs, cavern bottom tag
  - Regulatory requirements for periodic caverns re-certification
  - To be coupled with well integrity monitoring, WIMS.
- **Risk Register & Contigency Plan.**
  - Risk Register, Identification of worst case scenarios and repair options.
  - Follow up action plan
  - Management of abnormal events.
- **Audits.**
- **Continuous Learning Process**