Long term monitoring strategy and modelling assessment for underground radioactive waste repository

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Combined Monitoring and Modelling Network Meeting
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Content

Andra & Cigéo project overview

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Main project: Cigeo repository

A deep underground repository scientifically based on:
- local investigations & modeling in geology,
- phenomenology simulation,
- monitoring solutions.

To insure:
- operational safety \(~120\) years
- reversibility
- long term safety \(~10^6\) years

Against the radionuclide transfers:
- 1\textsuperscript{st} barrier: cells structure (concrete …)
- Final barrier: host rock (clay)
Short notions of French geology: General context of the Meuse/Haute-Marne region

**Attractive geological structure:**

- Host formation between carbonates formations with **low permeability**.
- Delimited regional faults
- Horizontality of the layer (~ 1.5° of inclination)
- Low velocity of tectonic deformation
- No seismicity

**Callovo-Oxfordian:**

- ~150 millions years old

**Depth:**
- 450 to 560 m under ground

**Clay-stone**

- 40 to 50% Clays
- 25% Carbonates
- 25% Quartz

**Depth:**
- 450 to 560 m under ground

**Callovo-Oxfordian:**

- ~150 millions years old
Geological investigations

- **Boreholes**
  - Measuring physical properties of the rock
  - Analyze the chemical characteristics of fluids
  - Perform hydrogeological tests to determine static and dynamic parameters of aquifers

- **Seismic campaigns**
  - Determine the geometry of the layers
  - Detect the presence & geometry of faults
  - Estimate physical properties of the layers

- **Underground laboratory**
  - Studying the lithology, physical and chemical variability
  - Study the physical processes (diffusion, coupling THM) in the long term
  - Characterize the excavated damaged zone (EDZ)

**Geological model for**

- Geometry of layers and faults
- Migration properties (porosity, permeability, diffusion), mechanical and thermal
- Estimation of uncertainties

**Use as an input for**
- Positioning the repository and structures (access galleries, shaft and ramp) in X,Y & Z
- Long term phenomena’s evolution simulations

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Modeling of Callovo-Oxfordian (COX) clay parameters

Geological, thermal parameters and hydro-dispersive:

- Clay content
- Permeability to water
- Thermal conductivity & heat capacity
- Porosity accessible to diffusion & effective diffusion coefficient of anions & tritiated water (HTO)

**Gocad**

*Mesh size: 6m*

*ZIRA dimension: 4 km x 5 km*
Context of numerical simulation at Andra

Preferential tool for

1. Representation of **phenomenological** evolution (PARS method)

2. Choice of **concept** and **design**

3. **Performance/Safety** Assessment

4. Design and interpretation of **experiments**, in particular in URL

Numerous kinds of simulation:
- **Phenomenological** simulations
  - representation & evolution of the repository, geological environment expected…
- **Performance** simulations
  - functional analysis, coupling physical process, components …
- **Safety** simulations
  - radiological impact to human being, scenario and situations assessed …
Development of methods and tools (internal Cassandra platform and specific codes: Code_Bright, Flac3D, CAST3M …)
ILLW disposal cell – 2D slice

Performance Assessment example

- Temperature profile (°C)
  - Without H coupling
  - With H coupling
  - H → T: very weak

- Saturation profile
  - Without T coupling
  - With T coupling
  - T → H: change

Code TOUGH2_MP

DRD/MTD/14-0151
Monitoring context

Monitoring strategy answers to several demands from French government and public

- 2006 Planning acts on management of radioactive waste and on transparency and security
- 2008 Safety Guide for disposal
- 2013 Public Debate

Monitoring strategy should adapt the Cigeo project next milestones

- 2017: Request for creation authorization (report submission to ASN - French Nuclear Safety Authority)
- 2024 to 2028: Operational qualification & testing => Industrial pilot phase
- 2028: First radioactive waste package put in cell

Monitoring program:

- **Controls of waste packages** (for compliance to specifications before acceptance), as well as their monitoring in disposal
- **Surveillance for operational security** and nuclear safety
- Monitoring as an input to reversibility management and long term safety assessment
- Monitoring of the environment
Monitoring objectives

» Contribute to operational safety (surveillance) and environmental protection

» Verify process evolutions in support of:
  - long term safety assessment
  - periodic re-evaluation of the repository safety and of its reversibility conditions
  - cells and gallery design optimization in the process of stepwise Cigéo construction

» Contribute to knowledge and understanding
  - Structures (galleries, cells) health and more specifically the interactions between structures and the host rock.
Technical monitoring objectives & parameters

Design of monitoring system

An iterative process during operating period

Disposal design (based on reversibility and long term safety)

Phenomenological Analysis of disposal situations

1. Feedback from monitoring and technology inventory

2. R&D monitoring

3. Qualification
   • In a laboratory
   • At the surface
   • In the URL
   • Metrology
   • Hardening

Identify processes to monitor

Monitor T-H-M-C-R

Substantial upstream knowledge (data, modeling, experience gained in Bure URL)
Principles for suitable structural monitoring

Monitoring data should be
- representative of the overall repository behavior and its spatial variability
- valuable for verifying the hypotheses of the safety case and reversibility performance

Monitoring systems should be
- at repository scale:
  - a reasonable density of instrumented cells (methodology for distributing instrumented structures)
- at cell scale:
  - an adapted density of embedded sensors: FMECA (Failure mode, effects, and criticality analysis) methodology for selecting high priority parameters
At repository scale

Optimized distribution of monitored cells:

- **Sacrificed cells**
  - “Active”/“Inactive” highly instrumented demonstrator cells
- **Witness cells**
  - Heavily instrumented reference structures
- **Current cells**
  - Average instrumented structures
- **Standard cells**
  - Regular structures

(MLW cells)
At cell scale

Constraints to take into account:

- Cell sealing:
  - Access to the cell only prior to waste storing
  - Cables and monitoring system should not compromise the safety (to avoid leakage for instance)

- Harsh environmental conditions (temperature, pressure, chemistry, irradiation...)

For each in situ technology, seek redundancy and complementarities

Monitoring will combines:

- Visual inspections, sampling
- Non destructive methods
- In-situ instrumentation

FMECA methodology: example of HLW packages retrievability

<table>
<thead>
<tr>
<th>Failure factor</th>
<th>P x S</th>
<th>Monitoring method envisaged</th>
<th>PxDxS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence of water in the cell</td>
<td>16</td>
<td>Sampling lines</td>
<td>64</td>
</tr>
<tr>
<td>Presence of H₂ in the cell</td>
<td>16</td>
<td>Sampling lines</td>
<td>32</td>
</tr>
<tr>
<td>Accumulation of corrosion products</td>
<td>12</td>
<td>Sacrificial cell</td>
<td>48</td>
</tr>
<tr>
<td>Blocking of the hatch by a foreign body (pad fragment or corrosion products)</td>
<td>10</td>
<td>Sacrificial cell</td>
<td>50</td>
</tr>
<tr>
<td>Loss of means of environment monitoring (taps)</td>
<td>8</td>
<td>Maintenance of sampling lines</td>
<td>40</td>
</tr>
<tr>
<td>Presence of H₂ in the head of the cell</td>
<td>10</td>
<td>Sampling lines</td>
<td>20</td>
</tr>
<tr>
<td>Deformation of the gallery with respect to the insert - potential misalignment of the cover bracket on the insert (monitoring reference)</td>
<td>10</td>
<td>Submerged extensometers</td>
<td>10</td>
</tr>
</tbody>
</table>

P: Probability of occurrence
S: Seriousness (difficulty regarding package removal)
D: ability to Detect the event (before it happens)

Score/5
Monitoring R&D studies overview

Majors studies on:
- sensors development (optical fiber sensors, TDR...)
- sensors metrology
- sensors hardening
- wireless transmission system & energy harvesting
- data mining & decision making

=> Use a TRL scale to set priority on monitoring system developments
Conclusion

Geological investigation and modeling
- comforts the repository location
- provide input data for long term evolution assessment of the repository

Simulations
- comfort the overall repository concept

Monitoring
- will provide useful data for operation period (safety, reversibility …)
- will provide input data to simulations (input parameters regarding the early stage of the simulation i.e.: first 100 years)
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