The research programme on argillaceous rock in France

Current status, future research needs

ESK-Workshop on German radioactive waste disposal research
20/01/2015

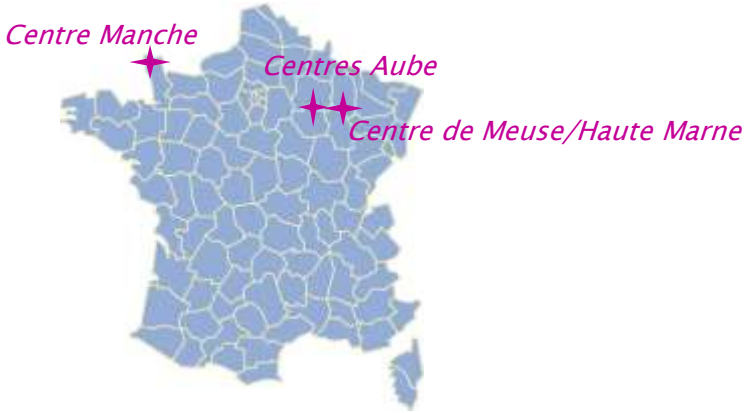
Andra's Disposal Projects

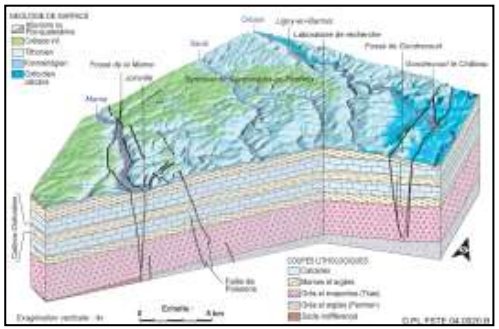
R&D Programme

2 disposal projects in clay

Cigéo Project (HLW/ILW-LL)

- Centre industriel de stockage réversible profond de déchets radioactifs en Meuse/Haute-Marne
  - Underground Research Laboratory
  - Long-lasting observatory of the environment (since 2009) + Ecothèque (since 2012)

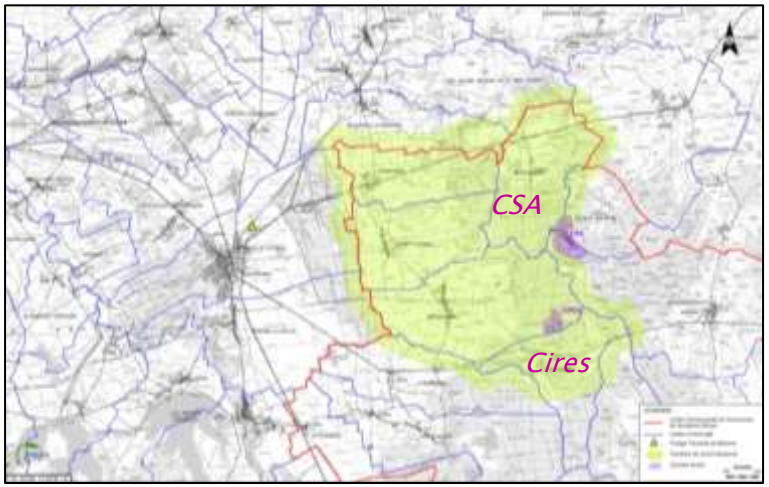




- Geological formation: Callovo-Oxfordian ~ 500 m depth and ~ 130 à 160 m thickness

Investigation on near surface disposal of « FAVL » waste (LLW-LL)

- Soulaine community
  - Geological survey under going



- Geological formation: argiles du Gault and argile à Plicathules

Geological disposal of HLW-ILW-LL: Major milestones

The 1991 Waste Act

- 3 research areas for High Level Long-lived Waste

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2025-2028: Pilot industrial operation phase without real waste

2029-2035…Pilot industrial operation phase with real waste

Siting the URL

1992-1994: Site screening for U/G research laboratories

- Consultation mission led by Member of Parliament Christian Bataille
- Site selection on the basis of voluntary sites
  - 2 types of rocks, 4 areas preselected :
    - Granite: Vienne
    - Clay: Gard, Meuse, Haute-Marne

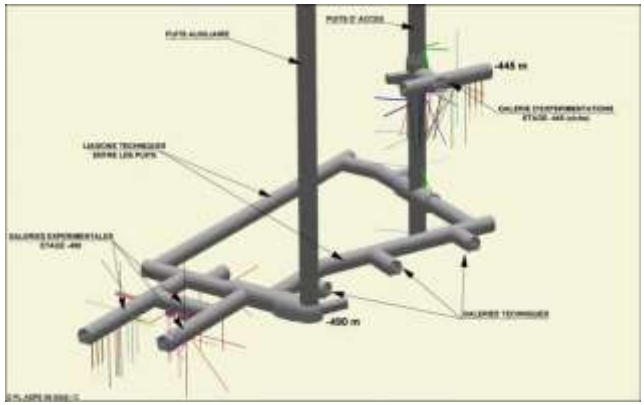
1994-1996: Above/ground geological survey in the 4 preselected areas, with regard to safety criteria

- 1996: Licence application for 3 URLs, reviewed by the National review board (CNE) and the French regulator (ASN)

1998: URL licenced in Meuse/Haute-Marne

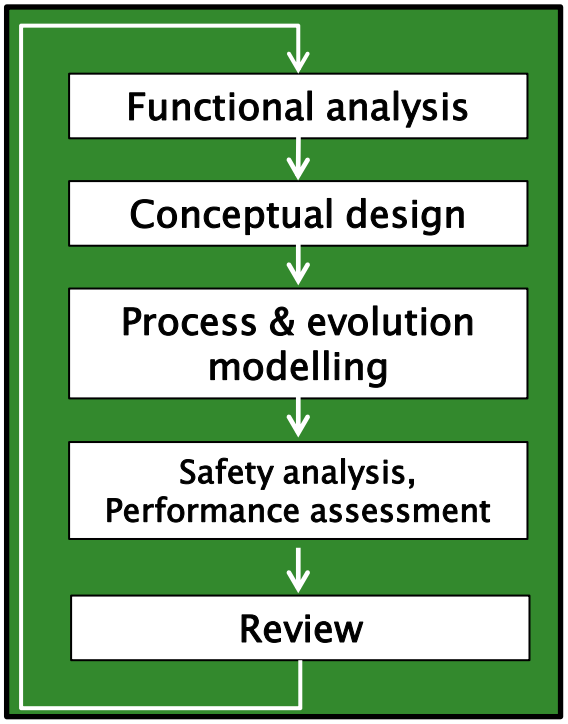
The Meuse/Haute-Marne URL: 1991-2005 period

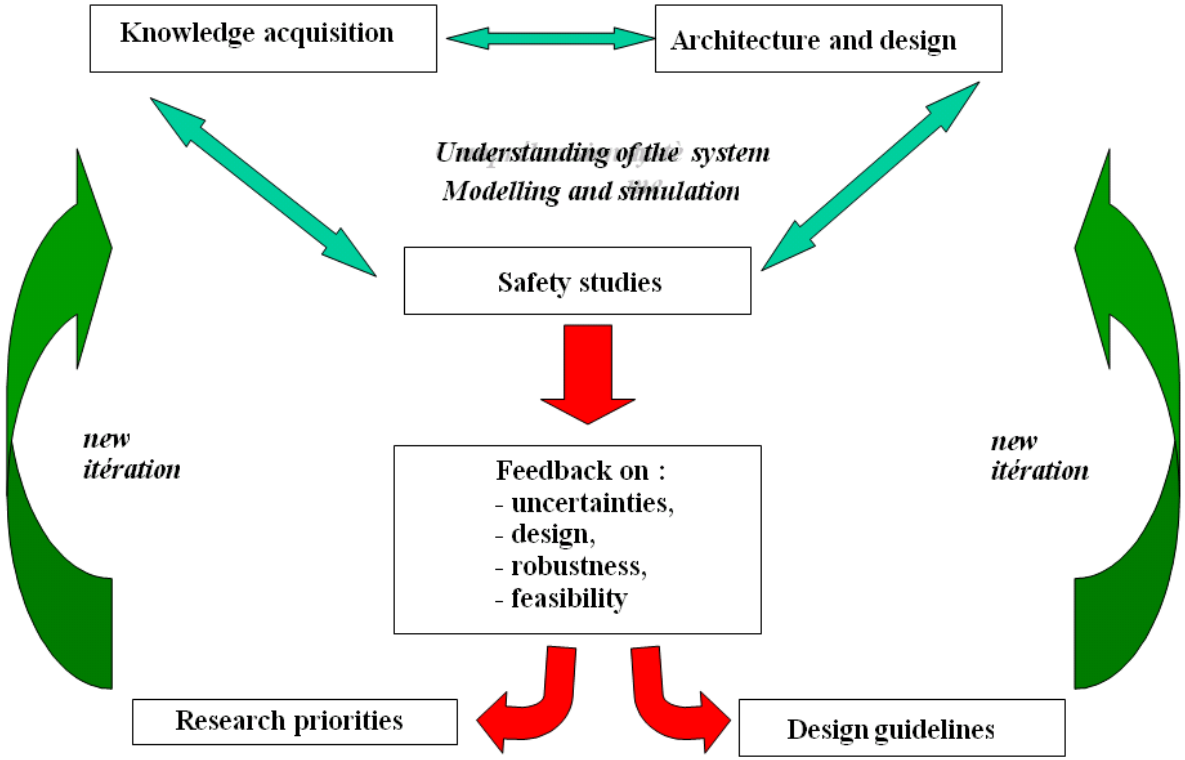
1998-2005: The construction and the operation of the URL made it possible to collect all basic data necessary for the feasibility and safety assessment provided in 2005.



A project combining scientific acquisition, design and safety

Design/safety iterations including national and international reviews: 1998, 2001, 2005, *2009*





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French HLW-ILW management scheme

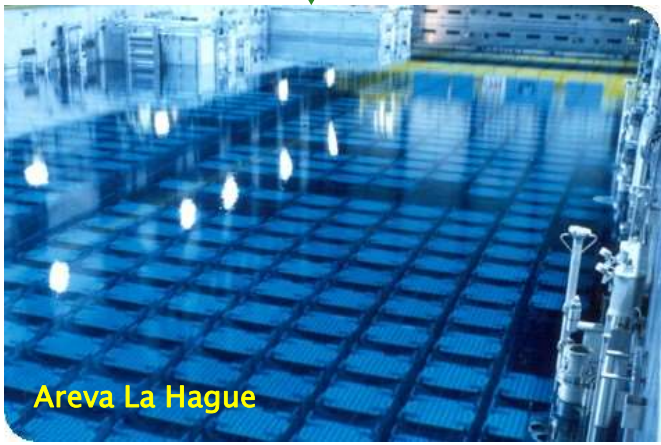
2006 Act

UOX fuel reprocessing, Pu+U recycling (MOX, URe)

Heat decrease storage of **final HLW**

Interim storage of **final ILW**

Interim storage of **reusable matter** (MOX SF)



French HLW-ILW management scheme

2006 Act

UOX fuel reprocessing, Pu+U recycling (MOX, URe)

Heat decrease storage of final HLW

- Early disposal of older HLW
- Disposal after 60-90 y. for currently produced HLW

- Vitrified fission products and minor actinides

Interim storage of final ILW

Disposal of ILW with a view to making the best use of storage capacities

- Fuel tubes, nozzels…
- Maintenance/dismantling waste
- Waste from liquid effluent treatment

Interim storage of reusable matter (MOX SF)

Reuse in GenIV reactors ?

P-T of minor actinides ?

Prospective studies of GenIV waste disposal

Heat decrease storage + disposal ?

As a precaution, direct disposal of spent fuel has been explored.

Planned Waste Inventory

- By law only end waste can be disposed of (no recyclable material)
- Cigeo is designed for the waste generated by existing nuclear facilities, under operation (50 years for PWR) or licensed

	Cigéo Inventory	
	Total volume to be disposed of (m^3)	Volume already produced in 2010 (m^3)
HLW	10 000	2 700
ILW	73 000	40 000

Vitrified HLW

MAVL

Clads, ends

Solidified effluents

Maintenance waste

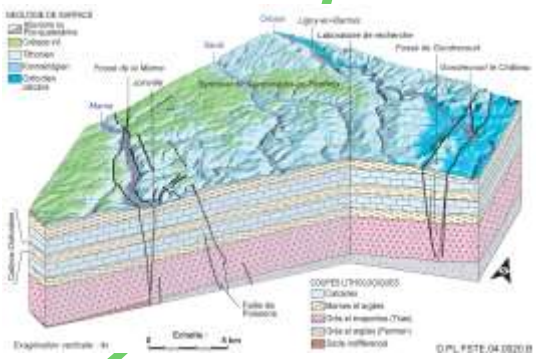
Activated waste and ITER

Siting Cigéo

Area defined after local consultation (2009) for location of repository U/G facilities and detailed geological survey from the surface

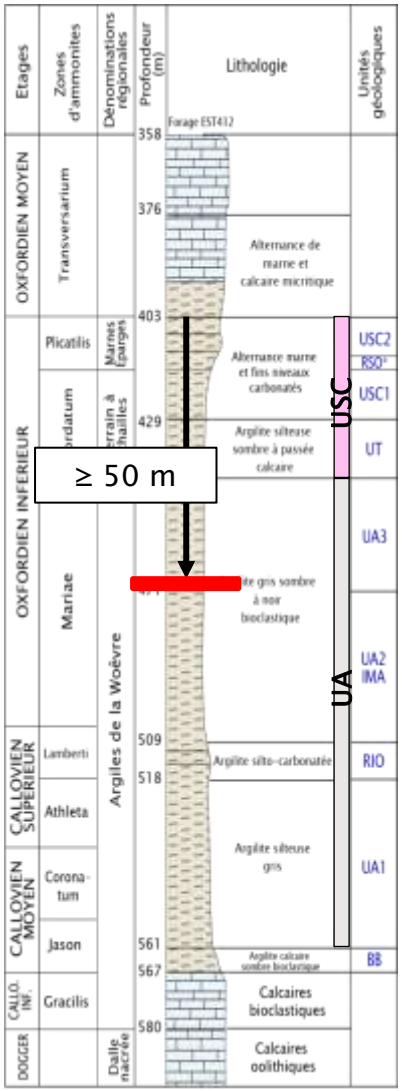
Location of repository surface facilities

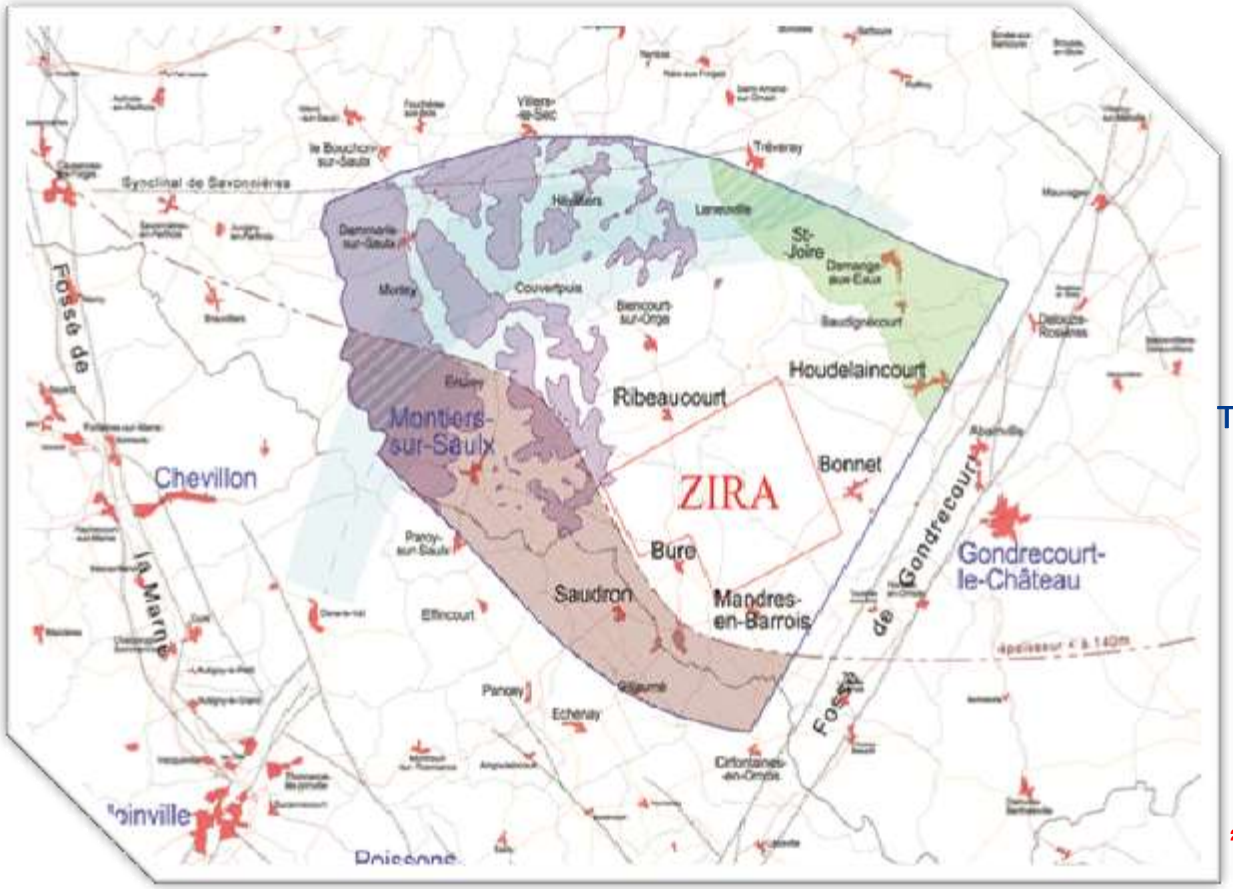
Transposition zone of URL results (proposed 2005)

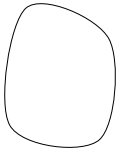


Siting started in 1992; URL licensed 1998

Siting Cigéo

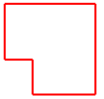






Transposition zone

≈ 250 km²



ZIRA

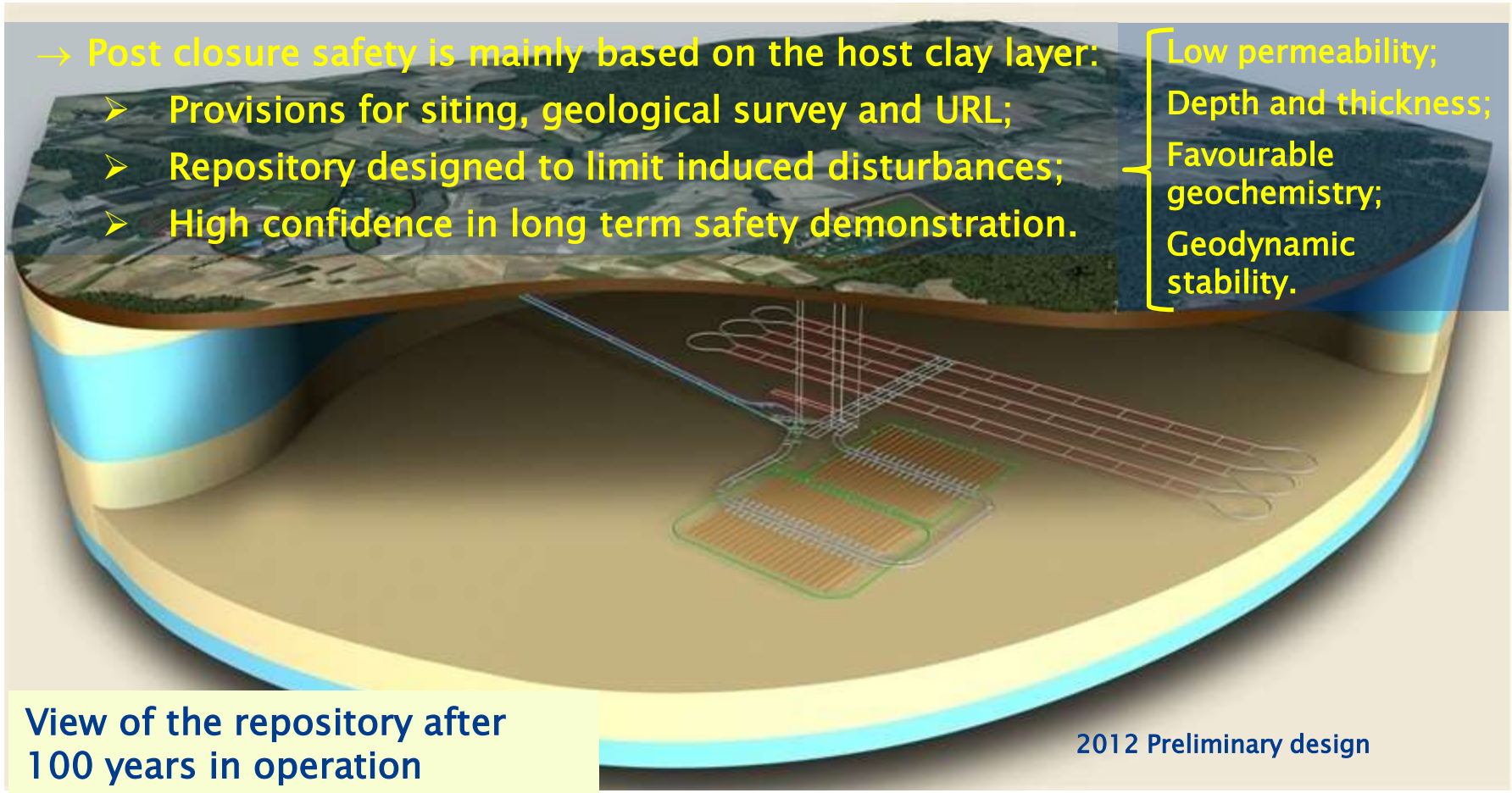
≈ 30 km²

The Cigéo project –layout

→ Post closure safety is mainly based on the host clay layer:

- Provisions for siting, geological survey and URL;
- Repository designed to limit induced disturbances;
- High confidence in long term safety demonstration.

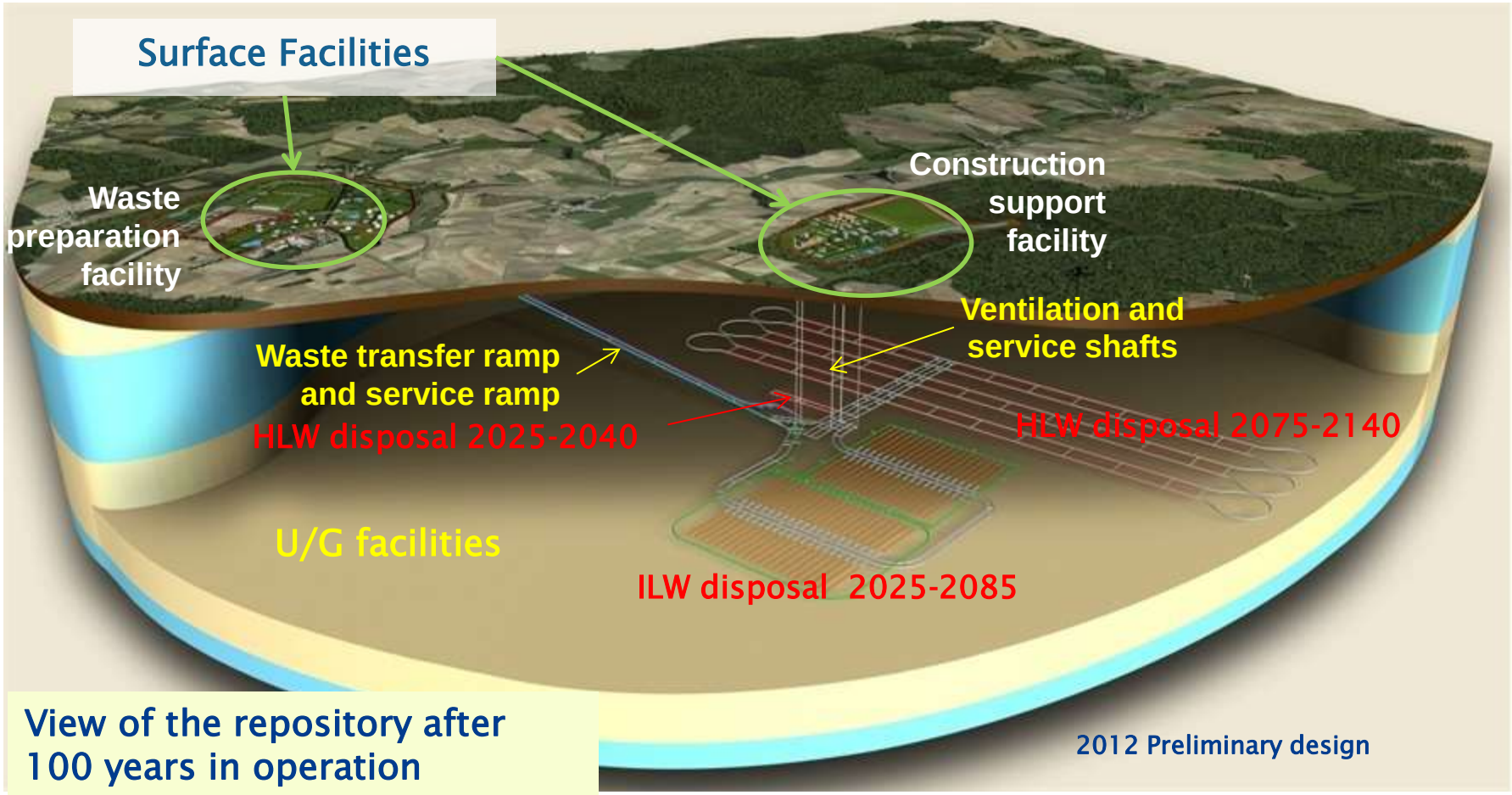
- Low permeability;
- Depth and thickness;
- Favourable geochemistry;
- Geodynamic stability.



View of the repository after 100 years in operation

2012 Preliminary design

The Cigéo project –layout

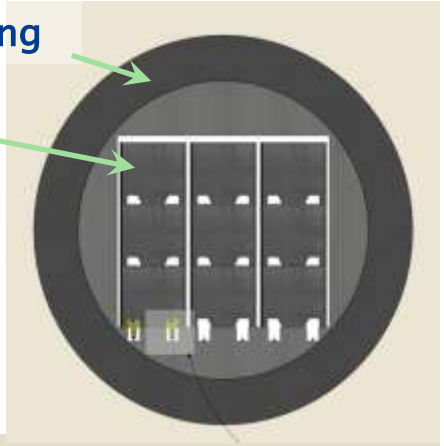


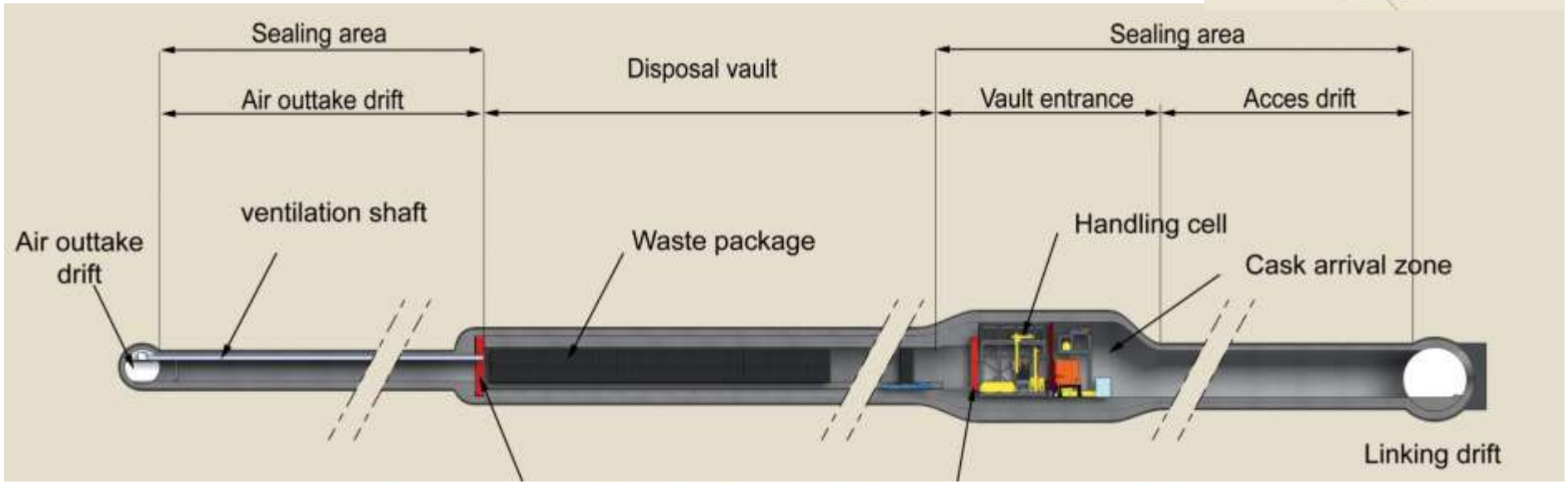
View of the repository after 100 years in operation

ILW-LL Disposal Cells

ILW disposal cells are horizontal tunnels located at the median of the host clay layer:

- Thick concrete lining to limit long term deformations;
- Ventilation of ILW repository cells as long as they are not closed.





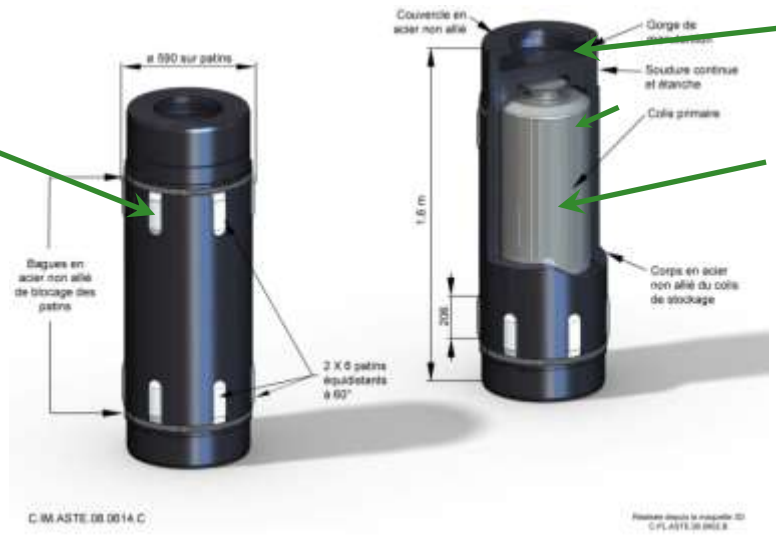
HLW Disposal Packages

HLW will be placed in 65mm steel overpacks to prevent glass leaching during the thermal phase:

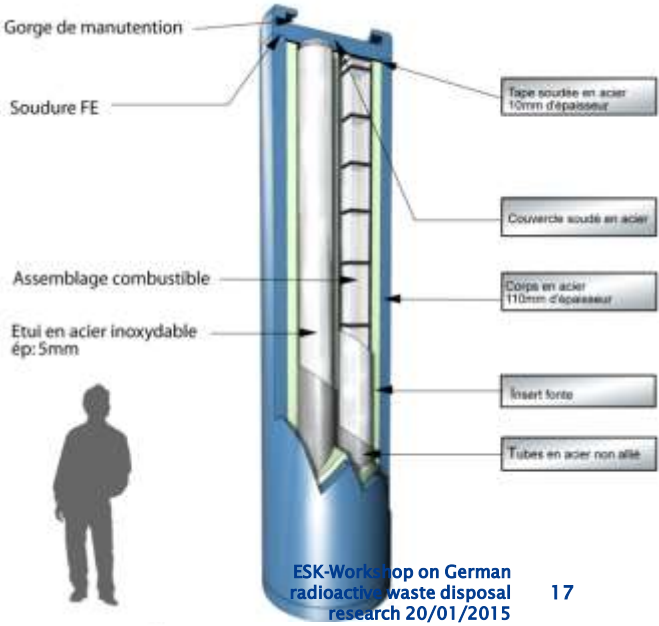
Ceramic skids for easy handling

Gripping Interface

Vitrified HLW Stainless Canister



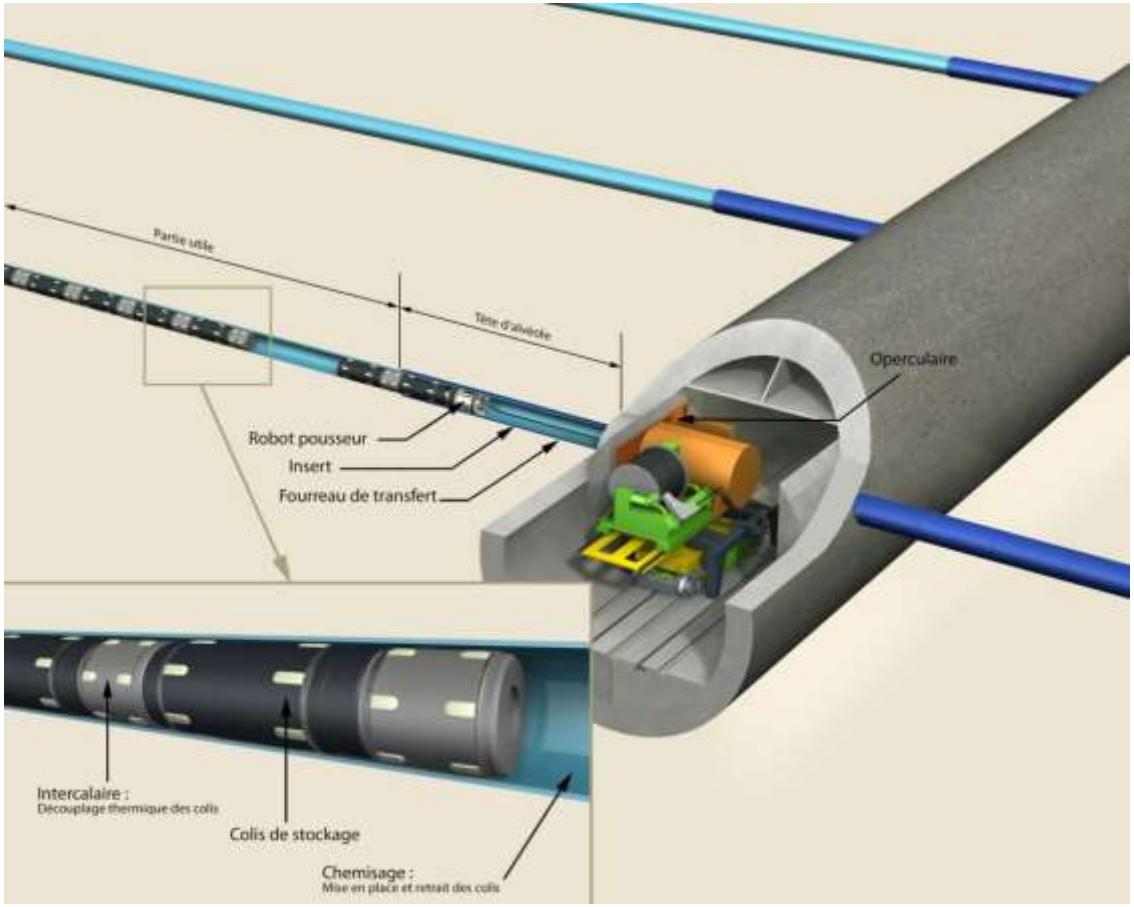
To explore the direct disposal option, steel containers have also been studied and prototyped for Spent Fuel



HLW Disposal Cells

HLW will be disposed of in lined horizontal micro-tunnels:

- Heat conduction in clay
  - max. temp in clay rock: 90 °C
  - Limitation of large scale THM effects
- Steel liner
- Cell length to be optimized with regard to technological limits and cost



2010-2012: Launch of the industrial design phase

2011: the results of 20 years of R&D have made it possible to issue detailed project technical requirements:

- Postclosure Safety,
- Nuclear safety and security in operation
- Waste emplacement and retrievability
- Control, monitor, observe
- Sustainable development, corporate and social responsibility
- Project governance

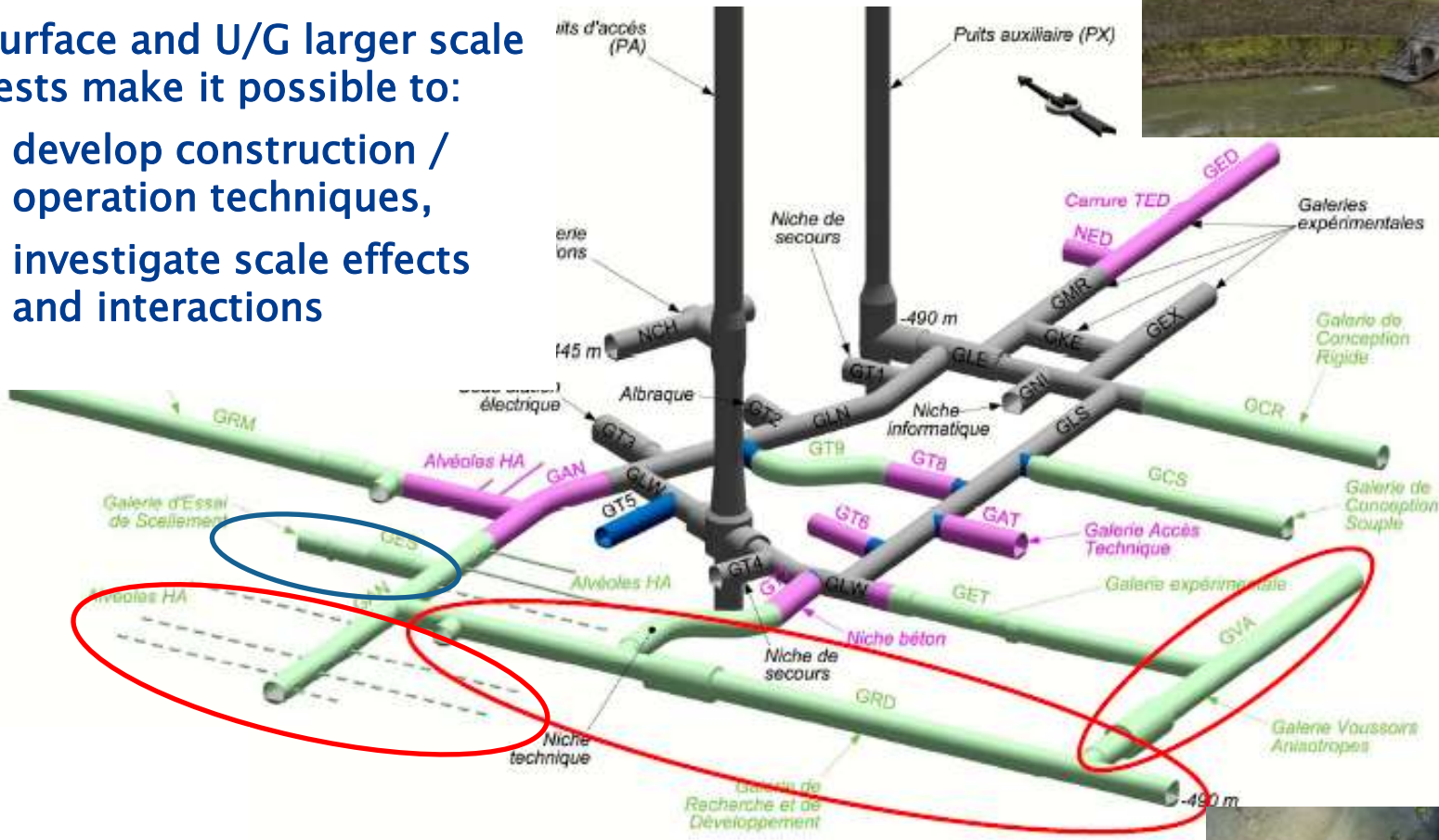
2012-2013: contracting agreements with engineering companies (overall system; conventional surface facilities; nuclear surface facilities; nuclear process; underground facility).

2013-2017: industrial detailed design

Current URL's objectives

Surface and U/G larger scale tests make it possible to:

- develop construction / operation techniques,
- investigate scale effects and interactions



Developments on repository construction techniques

Developments on repository sealing techniques

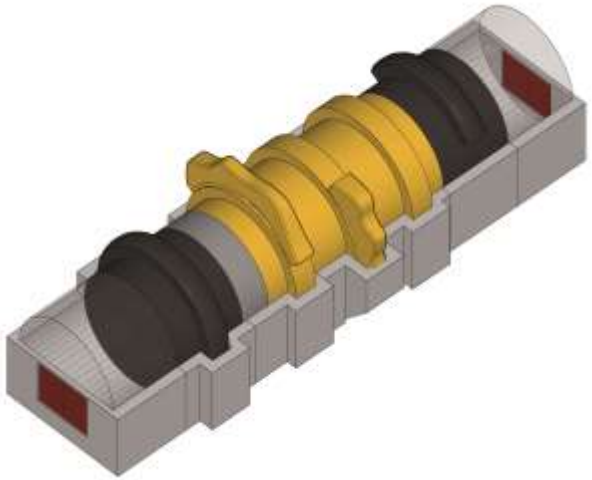
Excavation Techniques, Rock Support

TBM Test in the URL

HLW Microtunnel Construction Test in the URL

Drift Rock Support Tests in the URL

Sealing Technology and Demonstration Tests



Full Scale Test DOPAS* European Project
(Demonstration of plugs and seals)

Waste Package Handling

WDP Emplacement and Retrieval Tests

← ILW

HLW →

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Disposal Projects

Andra's R&D Programme: Overview

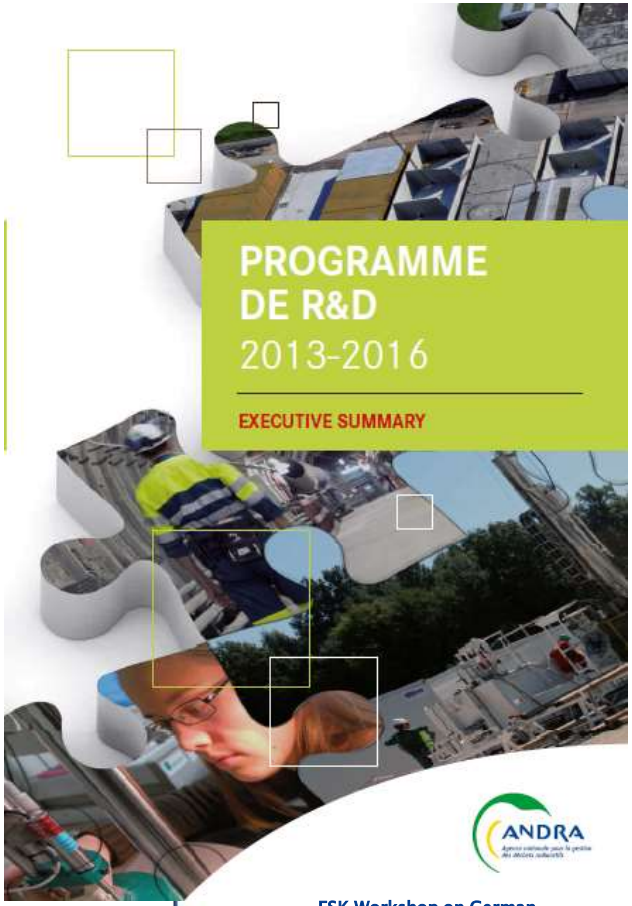
2013-2016 Andra's R&D Programme

Supports the Agency's disposal projects:

- The Cigeo geological disposal project for HLW and ILW-LL waste
- The investigation on LLW-LL disposal

And the operation of existing disposal facilities *(Periodic Safety Reports)*:

- Surface disposal facilities for LILW-SL waste
  (CSM and CSA)
- The VLLW waste disposal facility
  (Cires)



2013-2016 Andra's R&D Programme

5 priorities:

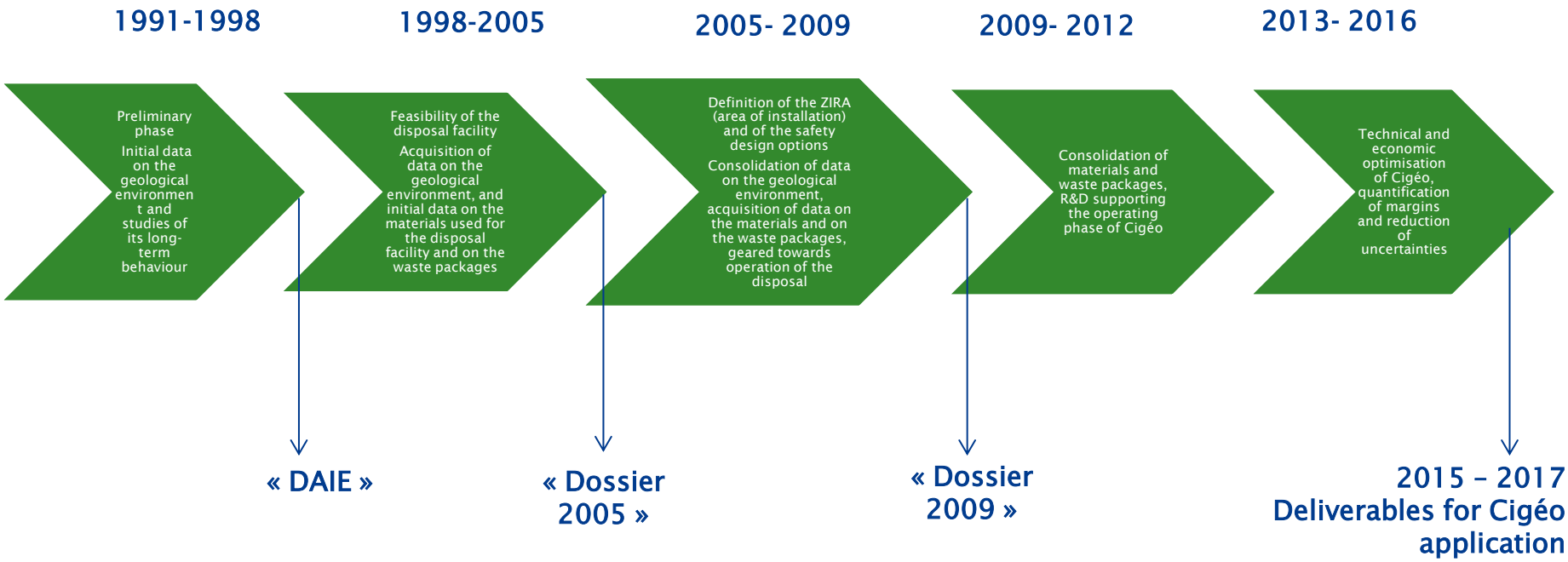
- Preserve the "rare resources" of disposal facilities
- Define requirements of disposal facilities and update them to reflect the current state of knowledge, optimize the design
- Support construction and operation of disposal facilities
- Collect and use data, monitoring systems and techniques
- Optimise the disposal materials

2013-2016 Andra's R&D Programme

- The programme relies on the Agency's R&D partnerships and on groups of laboratories to ensure (i) multi-disciplinary scientific representation (ii) involvement of the best scientific teams in research projects (iii) synergy of methods and skills (iv) long-term collaboration and (v) a tool guaranteeing transparency, performance and responsibility in governance and research at Andra.

Andra's R&D Programme is periodically updated

R&D Programmes
Geological environment and host rock, engineered materials, waste form



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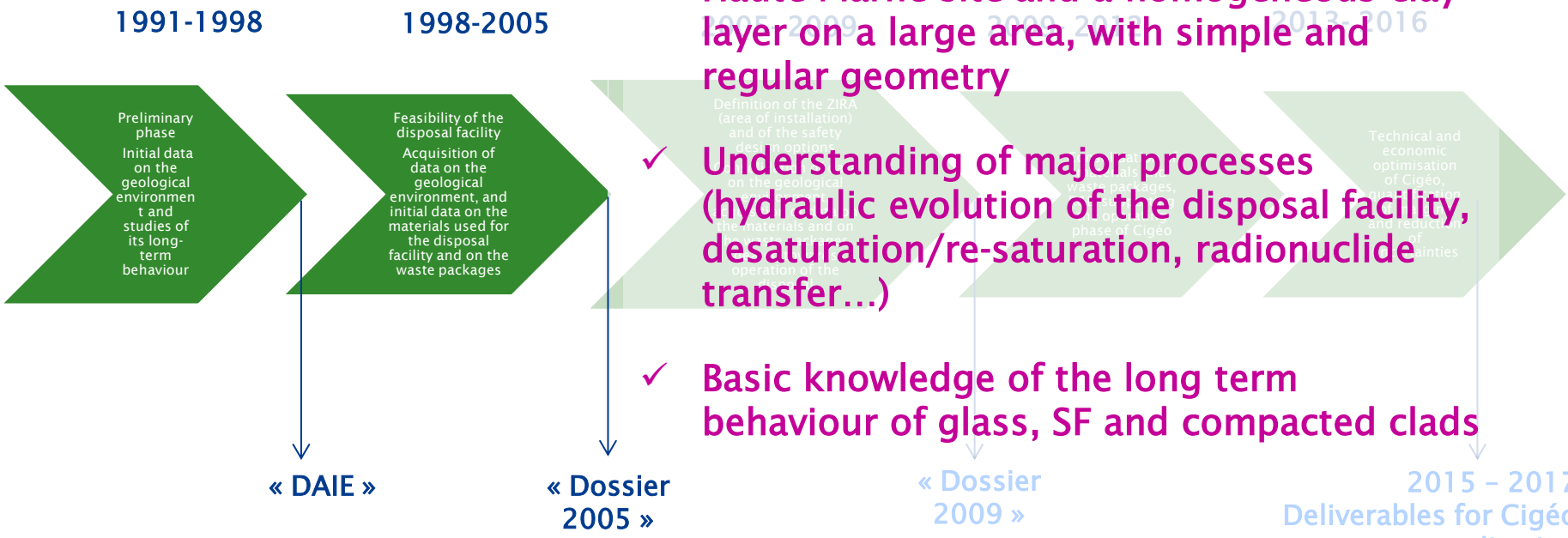

- ✓ Favourable characteristics of the Meuse Haute-Marne site and a homogeneous clay layer on a large area, with simple and regular geometry
- ✓ Understanding of major processes (hydraulic evolution of the disposal facility, desaturation/re-saturation, radionuclide transfer…)
- ✓ Basic knowledge of the long term behaviour of glass, SF and compacted clads

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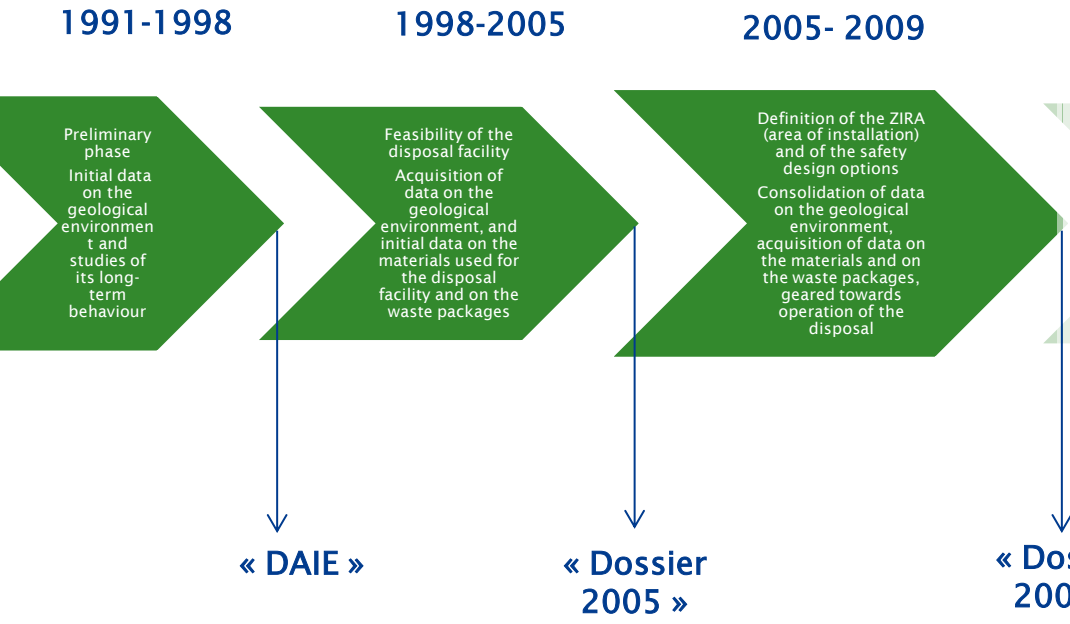
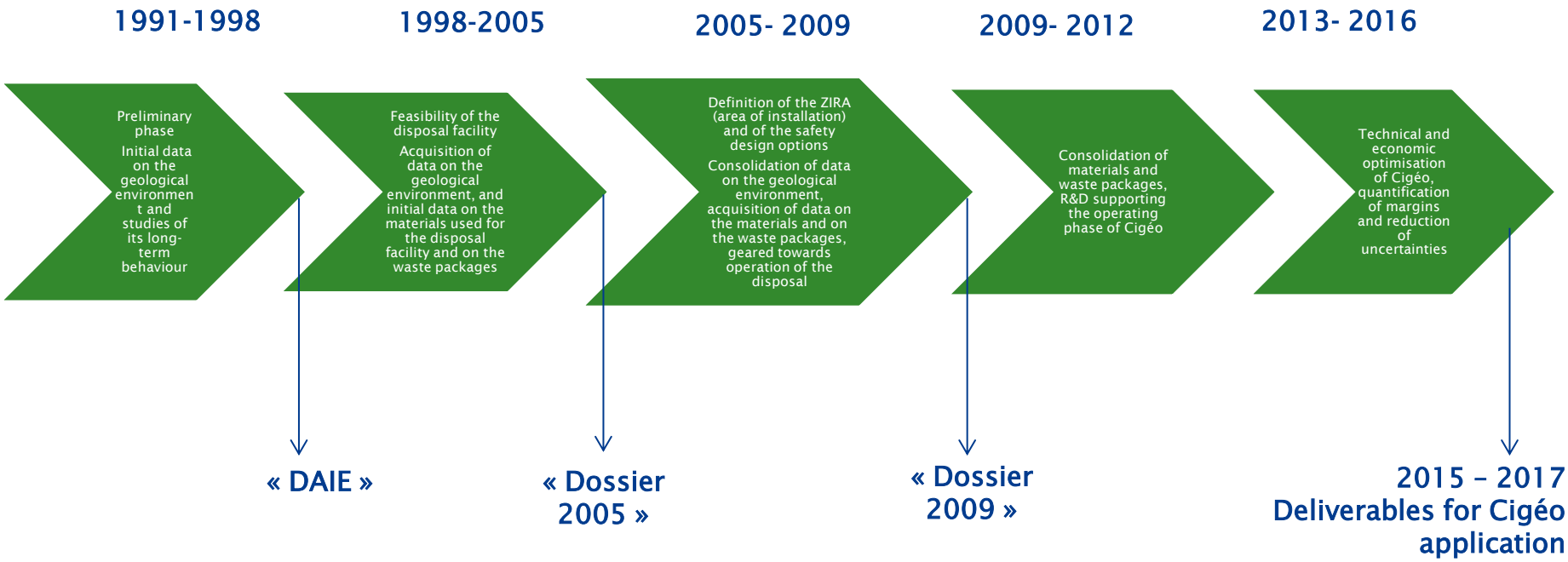


- ✓ Geological characteristics of the Meuse/Haute-Marne site suited to creation of a disposal facility
- ✓ Compliance with site criteria provided by basic safety rule (geological stability, very low water flow, absence of natural resources, high capacity for containment, ability to buffer chemical disturbances, mechanical resistance compatible with creation of U/G structures)
- ✓ Minimal disturbances induced by the construction and operation of a disposal facility

Andra's R&D Programme is periodically updated

R&D Programmes
Geological environment and host rock, engineered materials, waste form

Andra's R&D programme and its outcomes are reviewed by Andra's Scientific Advisory Board and submitted to the National review board (CNE)



2013-2016 Andra's R&D Programme

- Natural/engineered materials and behaviour of structures
- Processing/treatment of waste
- Monitoring, processing of information, databases
  - Innovative measurement techniques to develop an expert system to support decision-making and transmission of knowledge
- Simulation
- Environment and interfaces
- Social Sciences and Humanities (SSH)
  - Governance of waste and disposal systems

Waste packages

- Improve the characterization of the radiological inventory
  - Inventory in chlorine 36 and in iodine 129 (vitrified waste, spent fuel, graphite)
  - Inventory and speciation of the carbon 14 (hulls, graphite, REI)
- Develop processes of treatment and conditioning
  - Treatment of TRU maintenance organic waste
  - Treatment of graphite waste
  - Optimization of the management of dismantling waste
- Estimate more precisely gas build up
  - Reactive metals: aluminum, magnesium
  - Radiolysis of organic materials (polymers, bituminous waste)
  - Radiolysis of cimentitious materials
- Quantify the release of complexing species
  - Nature and having complexes power of the species not identified this day

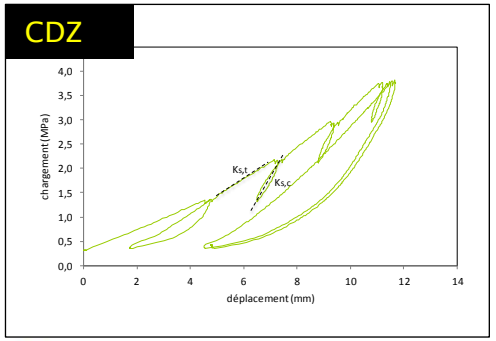
Waste packages

- Release of radionuclides
  - Vitrified waste
  - Corrosion of not reactive metals (alloys of zirconium, inconel, stainless and not allied steels)
    - Effect of the organic on corrosion rate
    - Risk and consequences of galvanic coupling
  - Waste graphite
    - Release of chlorine 36, carbon 14 and tritium
  - IRF of Mox fuel
    - At present between 30 and 50 %
    - Need to demonstrate the stability of U-Pu O_2 matrix containing fissile isotopes
- Thermal reactivity of bituminous waste
  - Reactivity of waste salts in temperature (fire hazard during operation)
- Swelling of bituminous waste in contact of water

Mechanical behaviour of claystones (damaged zone)

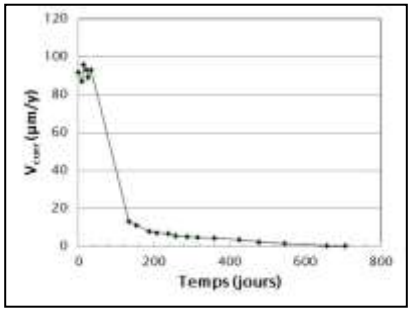
- Anisotropy, coupled THM behaviour, coupling of damage-swelling-creeping on extended paths and behaviour at crossing of the damaged zone,
- Damaged zone: **fractured system vs. "continuous system"**)
- Self-healing
- Transfer of gases
  - Consolidation of existing data on claystones and claystone/bentonite - concrete interfaces

- Main means of study
  - Tests in Underground Laboratory
    - testing different techniques of excavation/support/lining
      - » *Currently ongoing: OHZ, GGD, GCS, GCR, BPE, TPV…*
    - Compression / crossing test: ongoing CDZ: "gripper" test to follow
      - » *To follow: DPC, GVA, GER, GGD(2)*
  - Tests on different scales in surface laboratories plus theoretical developments

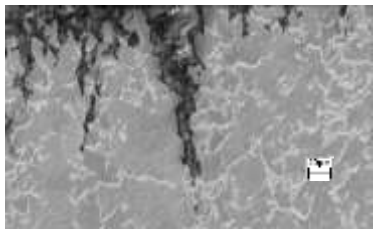


Corrosion of non-alloy or low-alloy steel

- Kinetics of corrosion in anoxic medium
  - Consolidation of low speeds (< 10 μm/year) and ot the duration of the raised kinetic transient
- Role of radiation (approx. 10 Gy/h), of micro-organisms or of local conditions (heterogeneity, cathode deposits)
- Risks of cracking under stress
  - Choices and tests of steel grades:
    - » *Liner API 5L X65MS (thermo-laminated steel, oil industry standard)*
    - » *Overpacks : P285NH (forged and stress-relieved steel)*
- Corrosion-mechanical coupling, especially when close to plasticity
  - Definition of macroscopic parameters



Vcorr in compact claystone, 90°C

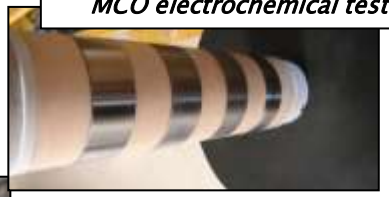


Cracks at the ferrite/perlite strips interface (non-optimised steel)

Main means of study

- Tests on demonstrators of liners and overpacks (body and welding)
- Tests in above-ground laboratories (especially by electrochemical techniques)
- Tests in URL
  - MCO tests ongoing and planned (especially by electrochemical techniques)

MCO electrochemical tests



Measurement of stress with sensitive carpet currently being developed

Chemical and chemical-mechanical behaviour of "low pH" concretes

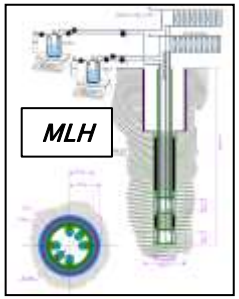
Low pH concretes *> e.g. CEM I cement base, with high proportion of mineral additions: blast furnace slag, silica fumes, fly ash. CEM I: 20 to 40 % - Additions 60 to 80%.*

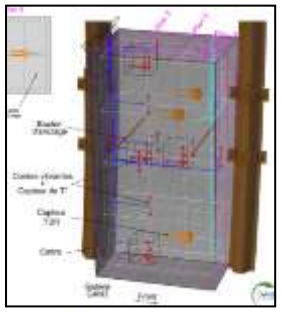
- Geochemical models of interactions and associated thermodynamic data, early behaviour
  - Validation of reaction drawings at interfaces
  - Validation of kinetics and extensions of modifications on both sides of concrete/claystone interfaces
- Chemical-mechanical coupling, particularly in relation to concrete/concrete and concrete/claystone friction
  - Definition of mechanical macroscopic parameters

Coupling of block upstream of

Main means of study

- Tests for technological (+ scientific) purposes
  - + *On surface >* ***FSS*** *(ongoing)*
  - + *At URL >* ***NSC*** *(≥2014)*
- Tests for scientific purposes at URL
  - + ***MLH tests*** *(ongoing)*
  - + ***BBP test*** *(≥2014)*



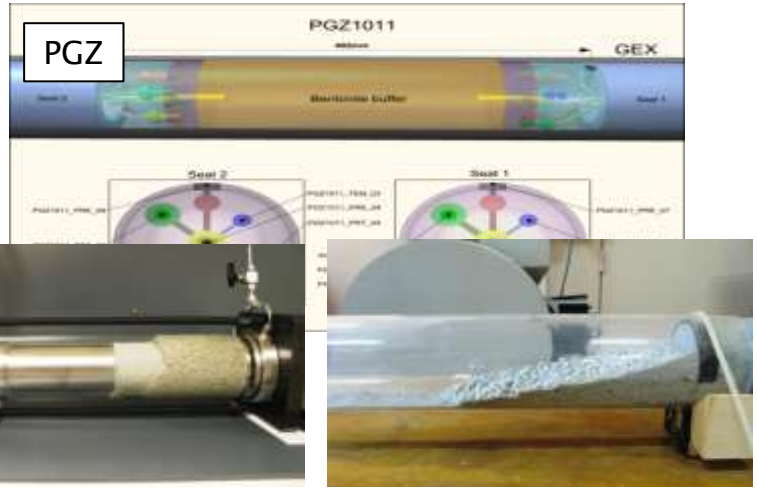


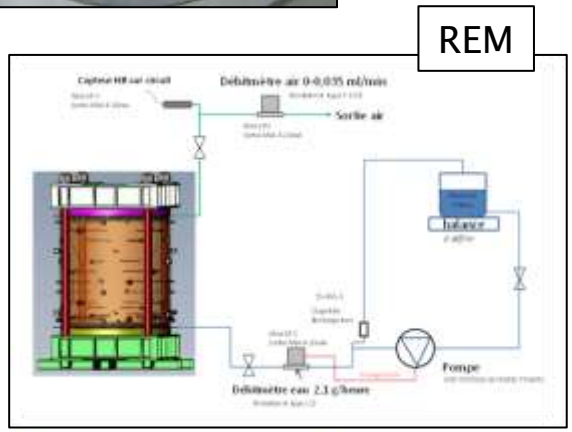
Hydromechanical-gaseous behaviour of bentonite powder/pellet mixes

- Hydromechanical behaviour
  - Characterisation of the parameters of "double porosity" models (e.g. BBM at UPC – Barcelona)
- Hydromechanical-gaseous behaviour
  - Characterisation of gas input pressures and hydric parameters

◆ Main means of study

- Tests at URL: new PGZ (≥ 2014)
- Metric model test above ground: REM





Complex chemistry of disposal cells for ILW-LL organic and salt waste

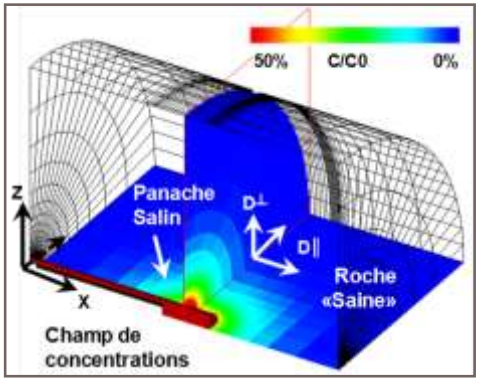
- Coupled behaviour in solution/retention of groups of organic solids and salts (thermodynamic and kinetic models and data), in cement-based medium and in claystone
- Associated behaviour of radionuclides (actinides)
  - Acquisition and validation of elementary data

Main means of study

- Acquisition of thermodynamic and kinetic data (thermo-chemical base)
- Experiments in above-ground laboratories (batches, centimetric cells, large diameter cells)

Cellule d'essais en acier

Découpage post-mortem
→ profils de concentration



Modélisation interprétative
→ détermination des paramètres de transfert

- Experiments in URL

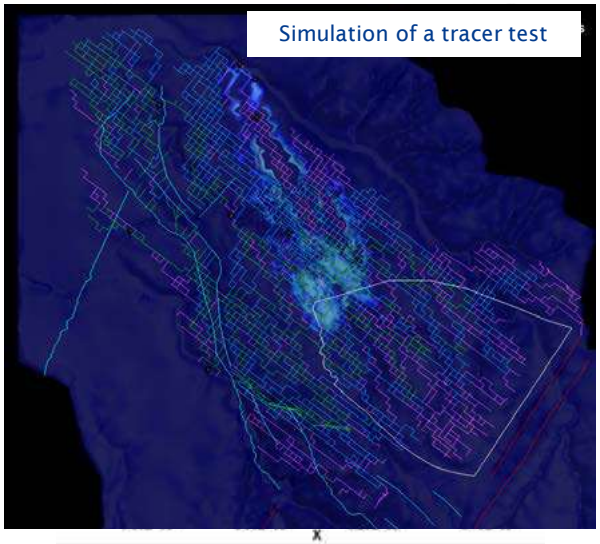
Karst aquifers of Barrois limestone

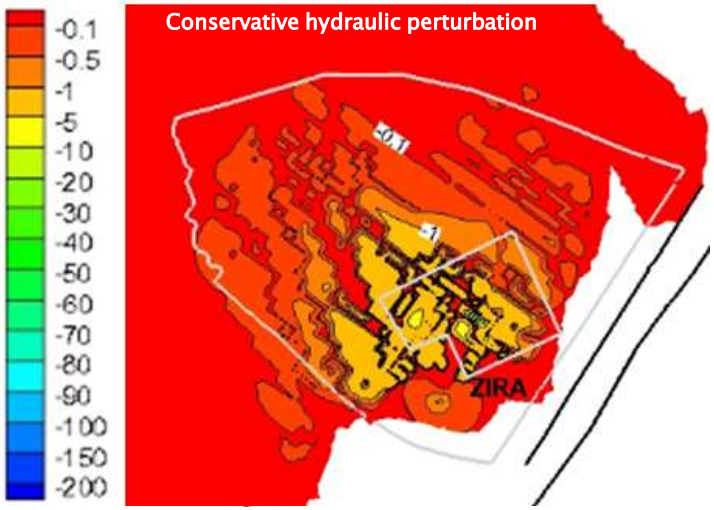
Characterization of karst and assessment of the repository hydro-impacts

- Karst networks geometry and flow
  - Construction of the 3D karst conduits based on geo-hydrological data and stochastic modelling
  - Reproduction of observed transient flow behavior

- Hydraulic impacts of engineered structures
  - Reproduction of the transient flow behaviour with respect to recorded (last 15 years) URL data
  - Position of tunnels and shafts with regard to karst distribution
  - Water flow prediction
    - During construction and operation;
    - After closure.

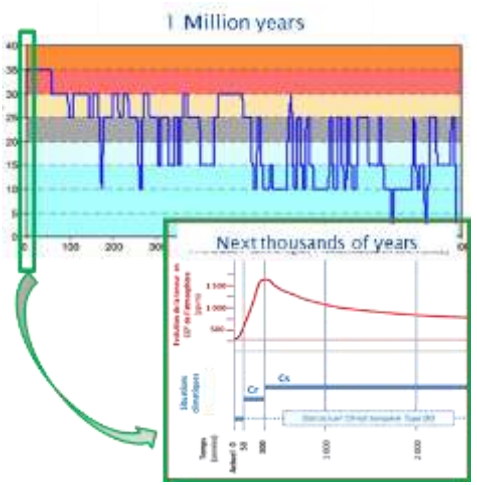
Karst networks of Barrois Limestone at Bure site





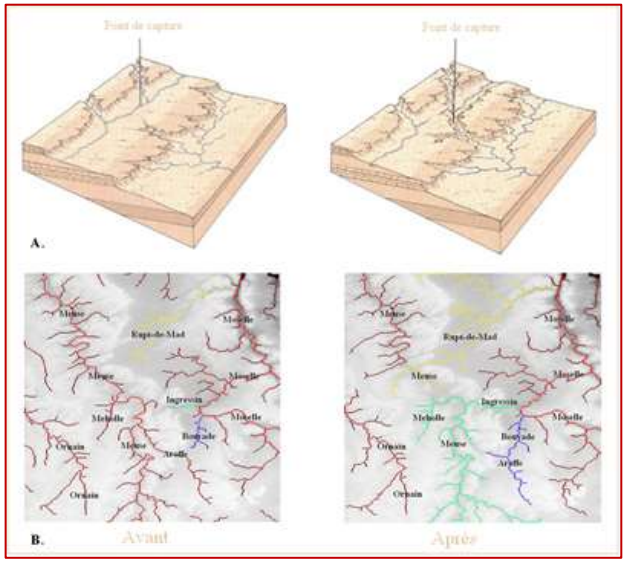
Internal and external geodynamic evolution

- Geomorphological Evolution: erosion and changes
  - Develop analyses and 3D / T simulations with fine stitch and small step of time for the near surface LLW-LL disposal concept
  - Refine the simulations of the future evolution of valleys on the million years for Cigéo site (possibilities of creation of new outlets)



Main means of study

- Studies of ground to reconstitute and quantify the evolution of the past in the relevant scales
  - Dating of superficial environnement
  - Method ESR for alluviums + colluvions
  - Geomorphological analyses
  - 3D modeller (Gocad)
- Digital simulations
  - Climate
    - » *Global model LOVECLIM and regionalization ; CEA/LSCE*
  - Geomorphologique evolution
    - » *Modellings phénoménolgiques3D / T (interfluves - reliefs)*

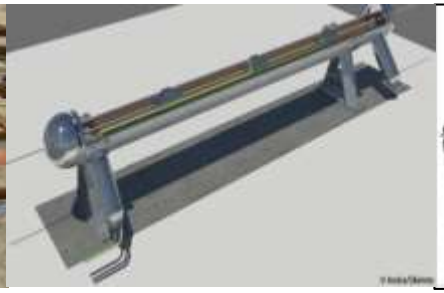
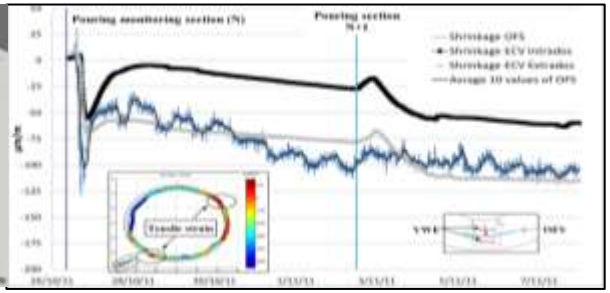


Monitoring, processing of information & databases

Pursuit of feasibility/pre-feasibility developments concerning **innovative monitoring**

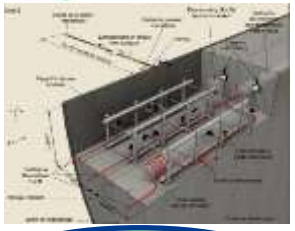
- Wired monitoring tools
- Mobile and remote methods (non-destructive)
- Wireless transmission
  - Major effort in relation to **optical fibres** for thermal, mechanical and chemical/gaseous measurements



- Main means of study
  - Tests in above-ground laboratory
  - Tests in URL
    - HLW cell 2016-2017
    - New tests in GER (concrete structures) in 2015
  - Partnerships: LNE; Iffsttar; etc.
  - Collaborations with EDF and Areva

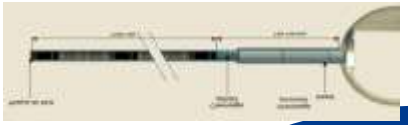
SAGD Expert (Acquisition & Data Management System)



Sensor1

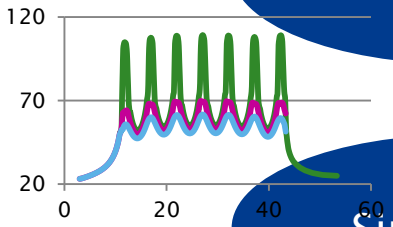
Sensor2

Standard



Parameter tuning

Model



Simulation

Computers to process raw data (coefficients, calibration…)

Acquisition systems

Data base

Data mining

In case of deviation:
« Red flag »

Nominal operating range? or gap?

Validated data

Measurement data comparison

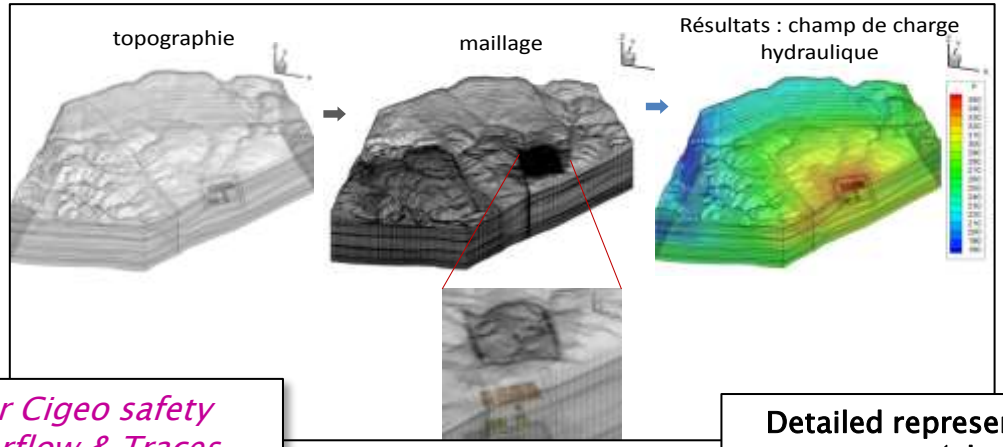
Breakdown?
Sensor drift?

- To optimize the monitoring system:
  - For the disposal cell but also for the overall repository
  - Determine the optimal number of cell to be monitored
- To establish structure health indicators
- To provide decision making tools

Simulation

Pursuit of effort concerning **High performance calculation** and **data processing** (*Reactive transport*, *diphasic water/H_2 transport, hydromechanical behaviour)*

- Digital Resolution Method
  - » *Decomposition of fields in space and time and parallel solvers*
  - » *Adapted meshing*
- Data processing methods
  - » *Decomposition of order moments > 2, local/global methods, reply surface, etc.*
  - » *Data mining*



Preparatory work for Cigeo safety calculations, with Porflow & Traces

Detailed representation of geological system (physical/geometric)
meshing of **3,000,000 elements**
CPU time = 5 days

Main means of study

- Partnership with INRIA (theses and post-docorates)
- ANR projects: e.g. H2MNO4 2013-2016 project (digital methods that perform correctly in reactive transport)

Environment

Understand and control the environment

- To prepare for license application and to establish the environmental surveillance plan
- To record and preserve environmental key samples for future use
- To improve dialogue with local communities
- To improve the global understanding of the environmental impact

Main means of study

- Develop and maintain a framework of environmental stations; **OPE** (Long Term environmental observatory)
  - Atmospheric station
  - Forest (Soil, forest biological cycle and solar flux,)
  - Grassland and crops (Soil, grass and crop cycles and solar flux,)
  - Biodiversity
  - Survey of land use changes through time (environmental and economic impacts)
- Build up and maintain a state of the art sample preservation facility (ECOTHEQUE)
- Maintain a framework of national and international collaborations

Social Sciences and Humanities (SSH)

- Management of proof
- Economy of long-term routes
- Governance of the disposal process (multiplicity of actors - confidence building)
  - Support for current and future debates: reversibility…

Thank you…