SAND2010-3555P

Advanced Conceptual and Numerical Methods for Modeling Subsurface Processes Regarding Nuclear Waste Repository Systems

IAEA Network of Centers of Excellence

Sandia National Laboratories

International Development Activities for Repositories in Clay and Crystalline Rock

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Briefing Outline

- Crystalline Rock Repository Development Activities
  - Sweden *
  - Finland *
  - Switzerland
  - Japan

* Regulatory/Performance Assessment Discussions

- Clay/Shale Repository Development Activities
  - France *
  - Switzerland *
  - Belgium

Long-term safety for disposal of HLW waste and spent fuel

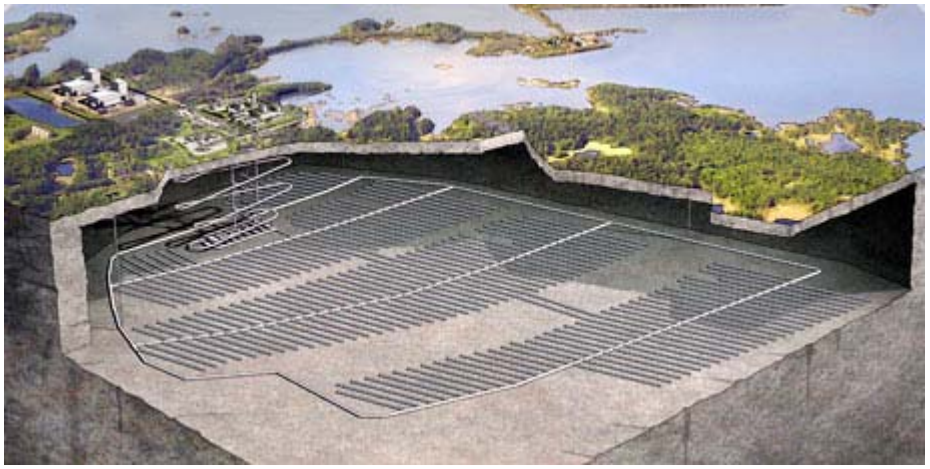
- Characterization and Siting
- URL Activities
- Regulatory Context
- Performance Assessment Results
- Important FEPs

Sweden - Nuclear Waste Management

- Sweden: 12 reactors (10 operating)
- Approximately 9,000 MTHM HLW (spent fuel) in 4,500 waste packages (6,000 analyzed)
- KBS-3 system concept (1983)
- Borehole emplacement
  - 2 MTHM/waste package
  - (Up to 10 MTHM/waste package can be achieved with larger packages and in-drift emplacement)
- Once-through LWR fuel cycle (no further reprocessing)

Sweden - Characterization and Siting

- **1985** CLAB (interim storage facility for HLW) Oskarshamn
- **1988** SFR (repository for LLW and ILW) Östhammar
- **pre-1992** site characterization (8 municipalities)
- **1992** Change to “voluntary” siting
- **1995** Äspö URL inaugurated

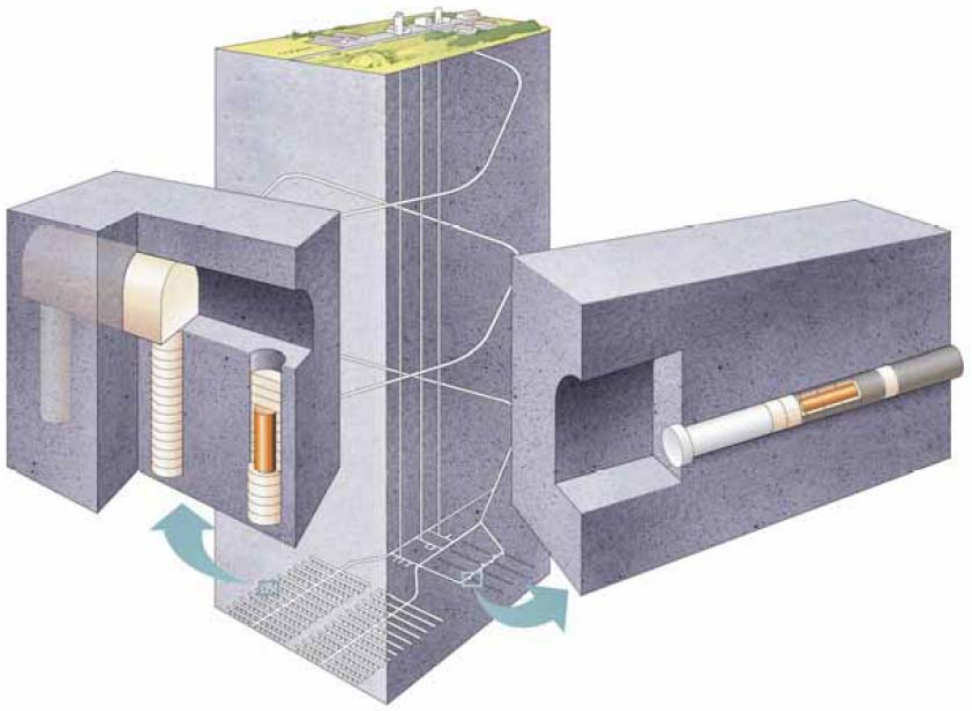


Conceptual View - Forsmark Repository, Power Station, and SFR

- **2002** Site characterization begins (Oskarshamn and Östhammar)
- **2006** Application for encapsulation facility (Oskarshamn)
- **2007** Site characterization complete
- **2009** Selected Forsmark (Östhammar) for final repository
- **2010** (planned) Application for repository permits
- **2015** (planned) Pilot-scale repository operation

Waste Isolation in Crystalline Rock: KBS-3 Concept

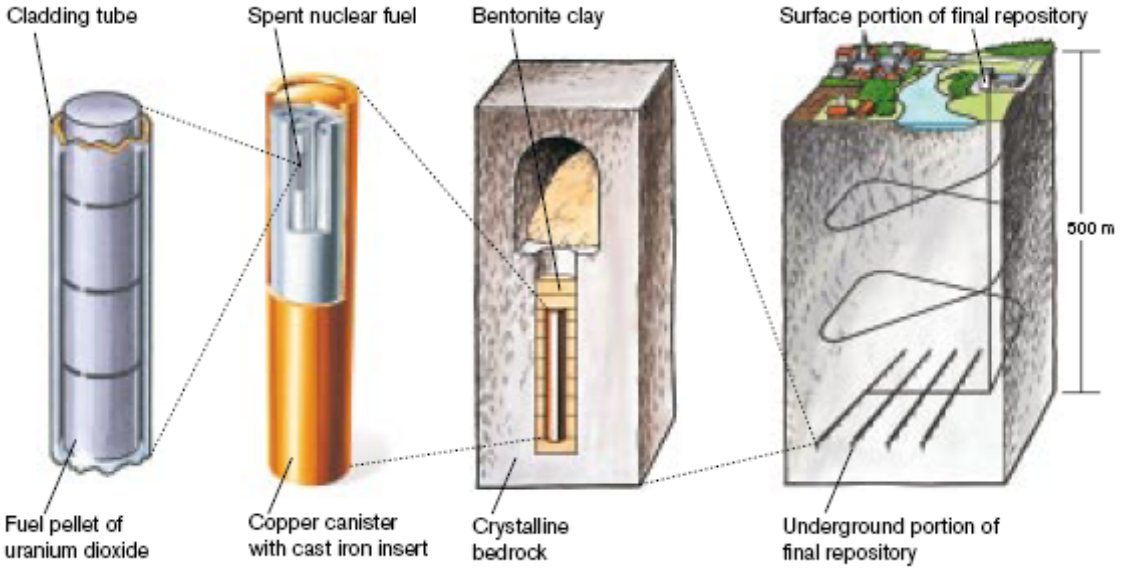
- Waste packages designed for chemically reducing conditions (Fe, Cu)
- Clay-based buffer material around waste packages
- Avoid emplacing waste packages in highly conductive faults or fractures



- Engineered clay-based backfill in access tunnels
- Borehole and shaft seals
- Vertical or horizontal emplacement

Waste Isolation in Crystalline Rock: Buffer Integrity

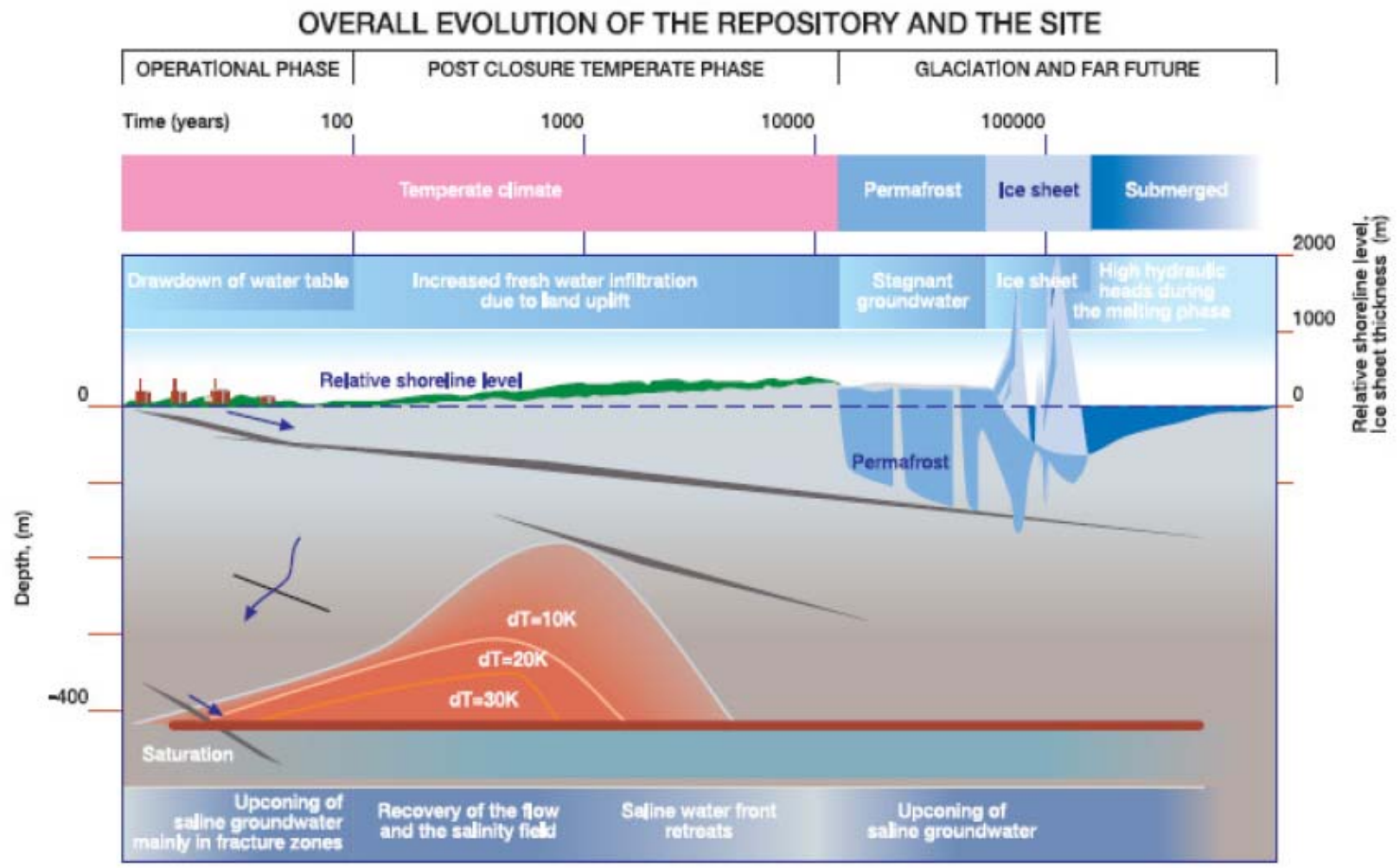
- Buffer degradation:
  - Inhomogeneous swelling
  - Piping
  - Colloidal Erosion
  - Creep
  - Liquefaction
  - Freezing



- Piping requires fracture water pressure > clay swelling pressure, plus a conduit for removal of buffer material. It can occur only during initial hydration.
- Swelling will be controlled by preparing buffer material in cohesive “bricks.”
- Colloidal erosion requires divalent cation concentrations < 1 mM.
- Models show that deviatoric creep (flow) occurs slowly in 100,000 yr.
- Liquefaction will be controlled by buffer density and swelling pressure.
- Freezing will not occur in situ.

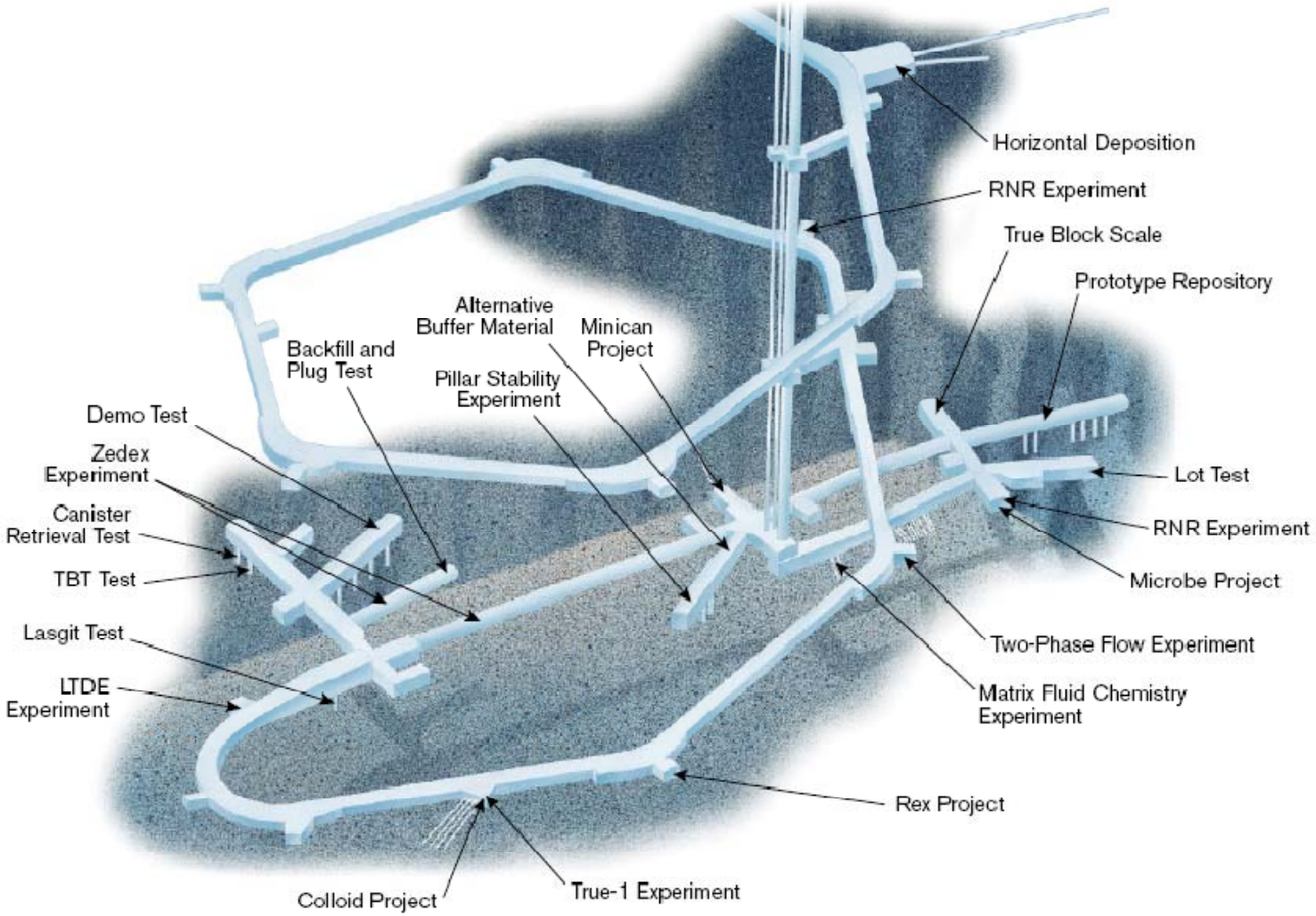
Source: SKB TR-06-09
(*http://www.skb.se/Templates/Standard____17139.aspx*)

Crystalline Rock Repository Postclosure Evolution



Source: Smith, P. et al. 2007. POSIVA 2007-06 (*http://www.posiva.fi/en/search?searchterms=kbs-3h*).

Äspö URL Layout

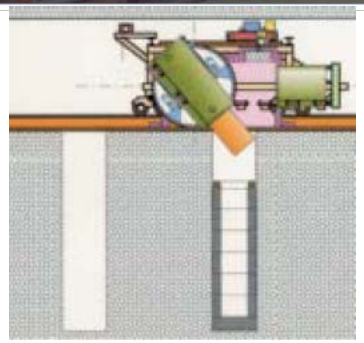


Äspö URL Research (Cont.)

- Prototype repository
  - Full-scale
  - Model testing

Äspö URL Research (Cont.)

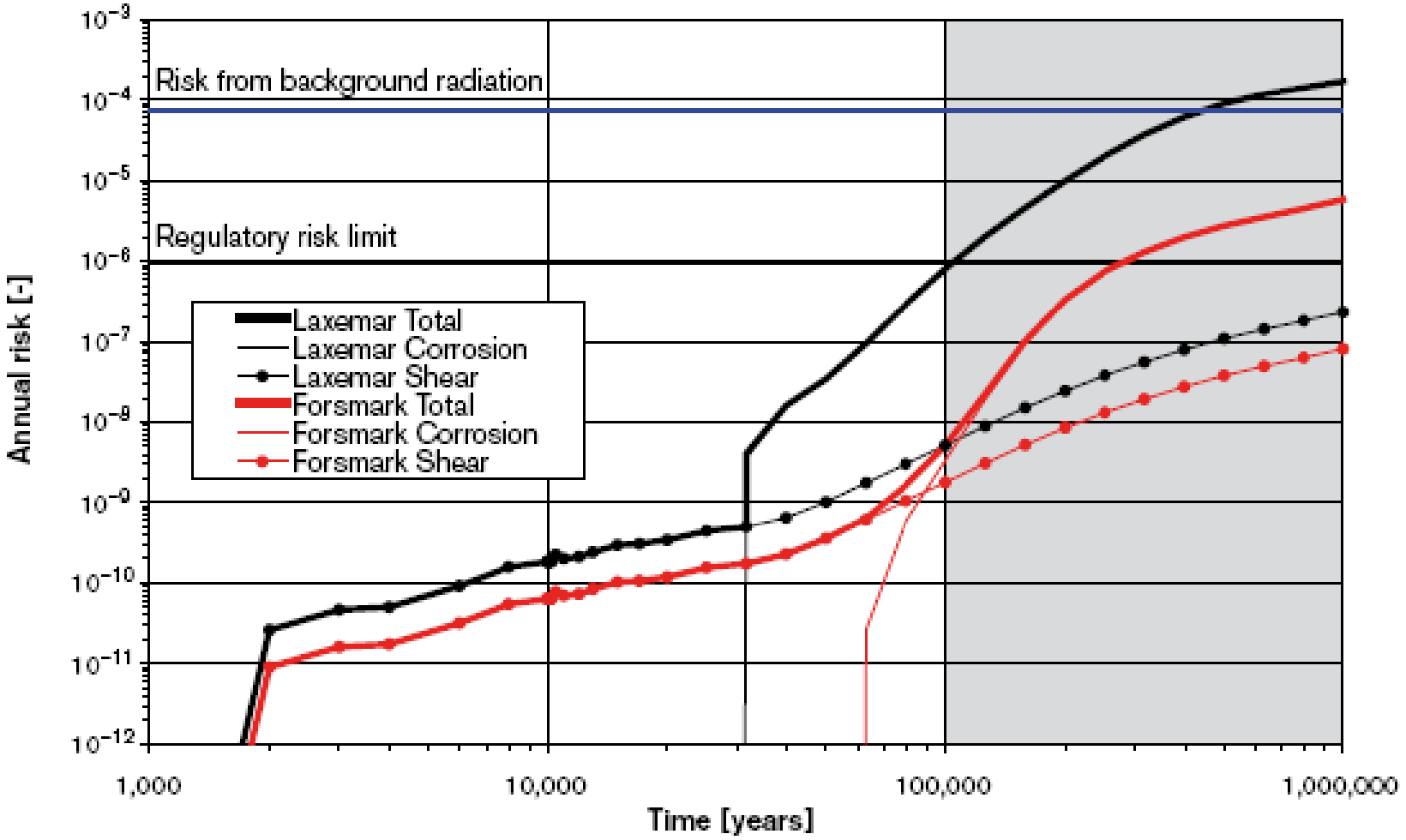
- Waste Handling
  - Horizontal emplacement
  - Vertical emplacement
  - Canister retrieval test



Sweden - Geologic Repository Regulatory Context

- Final repository dose-based standards:
  - Performance assessment with treatment of FEPs, uncertainty, sensitivity; term of assessment ≥ 10,000 yr (SKIFS 2002:1)
  - Probability of health effects (cancer, hereditary) to the reasonably exposed individual < 10^{-6}/yr, corresponding dose 1.4×10^{-5} Sv/yr = 1.4 mRem/yr (SSI FS 1998:1)
  - Quantitative dose standard for 100,000 yr; "qualitative" to 1 Myr
  - Comply with Swedish Act on Nuclear Activities
- 1999 Swedish Environmental Code
  - Perform Environmental Impact Analysis and submit permit applications for the final repository, SFR, and encapsulation facility

Sweden: SR-Can Performance Assessment



Source: SKB Technical Report TR-06-09

Sweden: Important FEPs in SR-Can Assessment

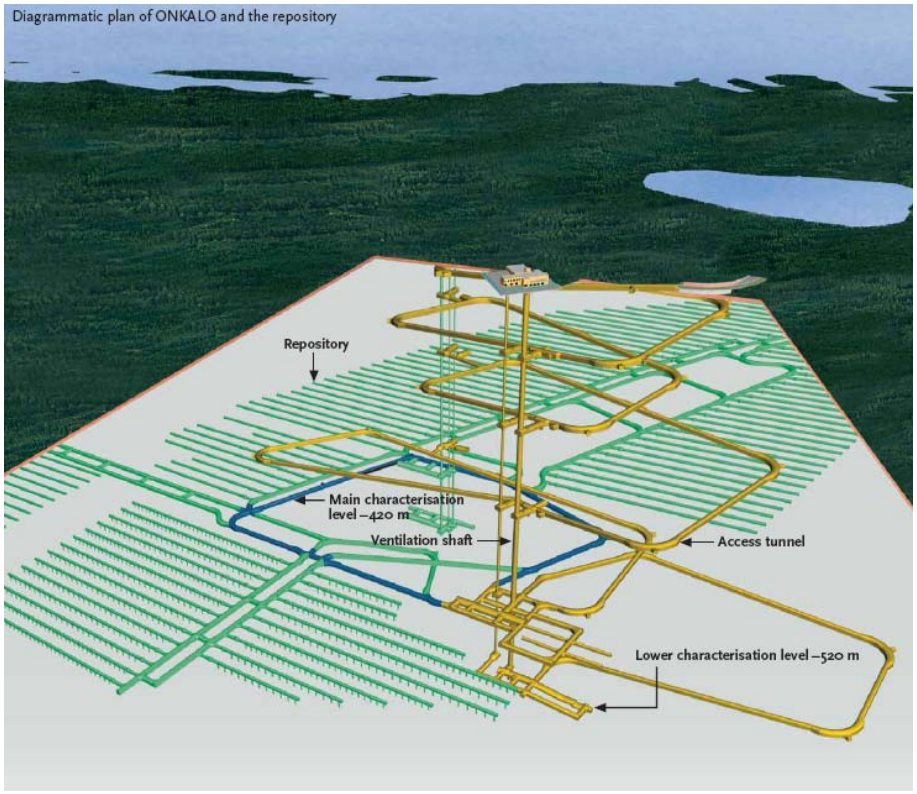
- **Relatively significant processes**
  - Buffer advection/canister corrosion
  - Future human activity
- **Insignificant processes**
  - Isostatic loading
  - Buffer freezing
  - Canister failure due to shear movement on fractures
- **Important uncertainties**
  - Buffer exposure to glacial melt waters
  - Intercepting fracture conducts glacial melt water
  - Buffer erosion
  - Mechanical response of fractures to glacial rebound
  - Ice-age biosphere

Finland - Nuclear Waste Management

- Finland: 5 reactors (4 operating, one in construction)
- Approximately 5,500 MTHM HLW (spent fuel) in 2,800 waste packages
- KBS-3H system concept proposed (2007)
- Borehole emplacement
  - 2 MTHM/waste package
  - (Up to 10 MTHM/waste package can be achieved with larger packages and in-drift emplacement)
- Once-through LWR fuel cycle (no reprocessing)

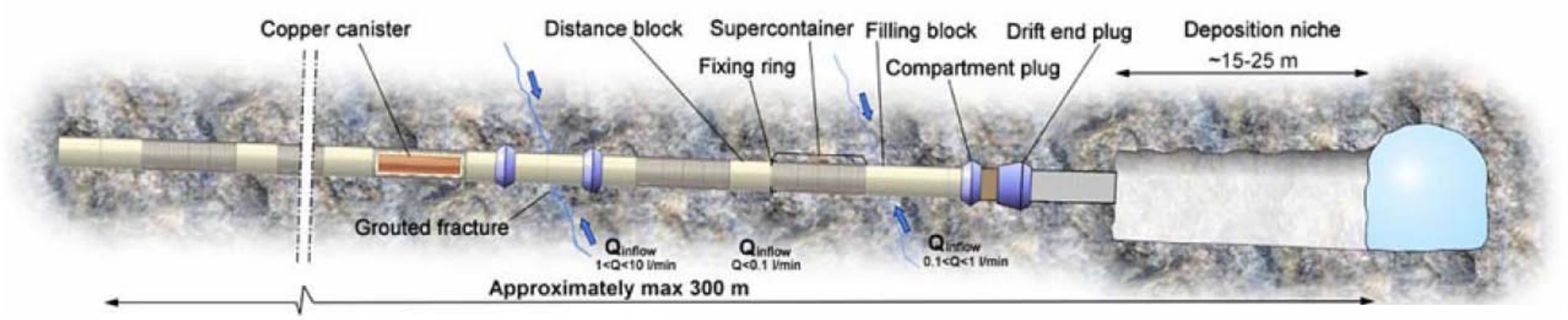
Finland - Characterization and Siting

- **1985** Completed screening all of Finland
- **1986** Began preliminary site investigations
- **1992** Completed site investigations
- **1993** Began detailed site investigations (4 sites)
- **1999** Submitted application for "decision-in-principle" for a final repository at Olkiluoto
- **2000** Completed site investigations and environmental studies (4 sites)

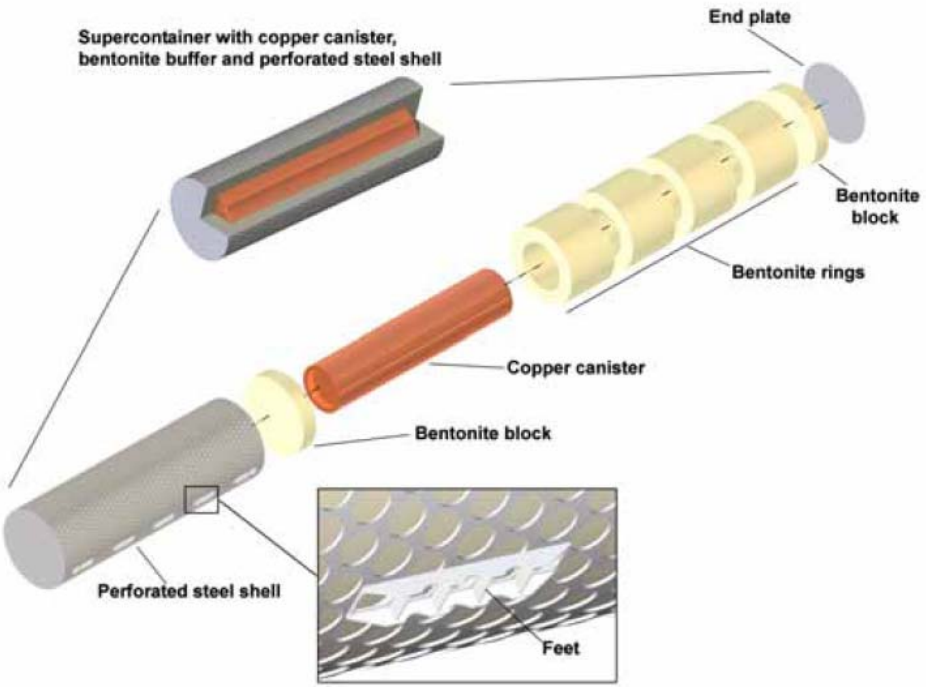


- **2004** Begin construction of ONKALO "Characterization Facility"
- **2011** Estimated completion of ONKALO
- **2012** Scheduled submittal of repository license application

Finland: Horizontal Borehole Emplacement

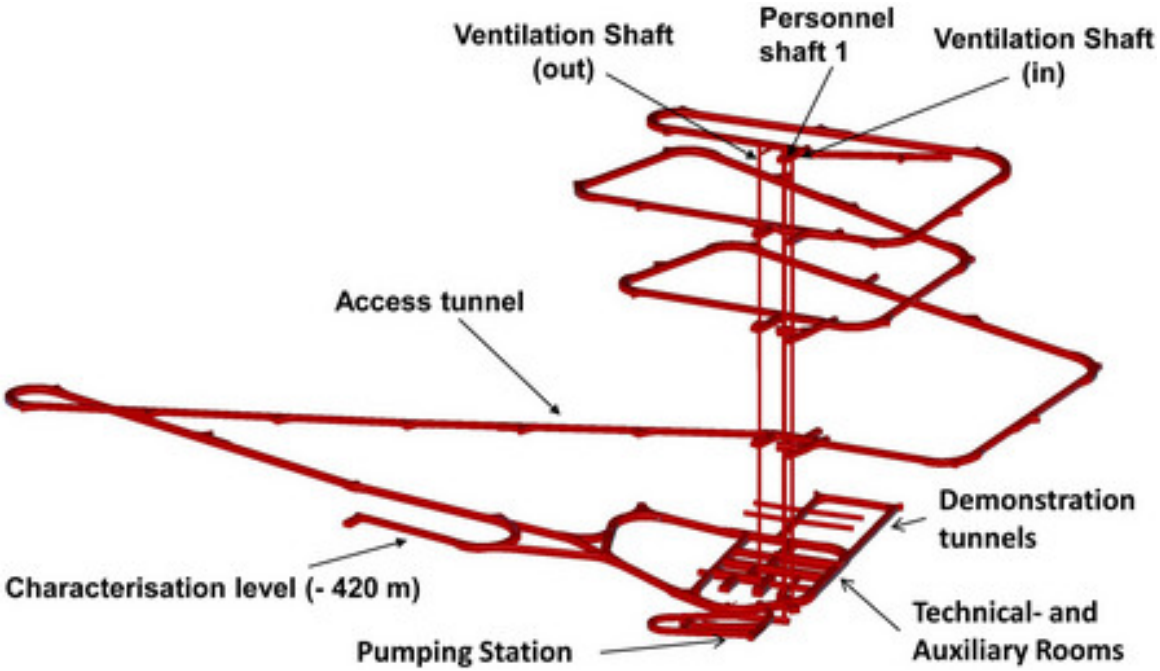


- Proposed KBS-3H concept
  - Horizontal tunnel or large-diameter borehole
  - "Supercontainer" combines canister and buffer
  - Plugs isolate conductive fractures



Finland: ONKALO Underground Characterization Facility

- Drill-and-blast excavation
- 1 access ramp
- 1 personnel shaft
- 2 ventilation shafts
- Tunnel slope 1:10
- Width 5.5 m
- Height 6.3 m



- Investigate geologic, hydrologic, geochemical, and geomechanical features of the host rock mass (ongoing)
- Develop excavation techniques and final disposal method
- Use the ONKALO facilities in the repository

Finland - Geologic Repository Regulatory Context

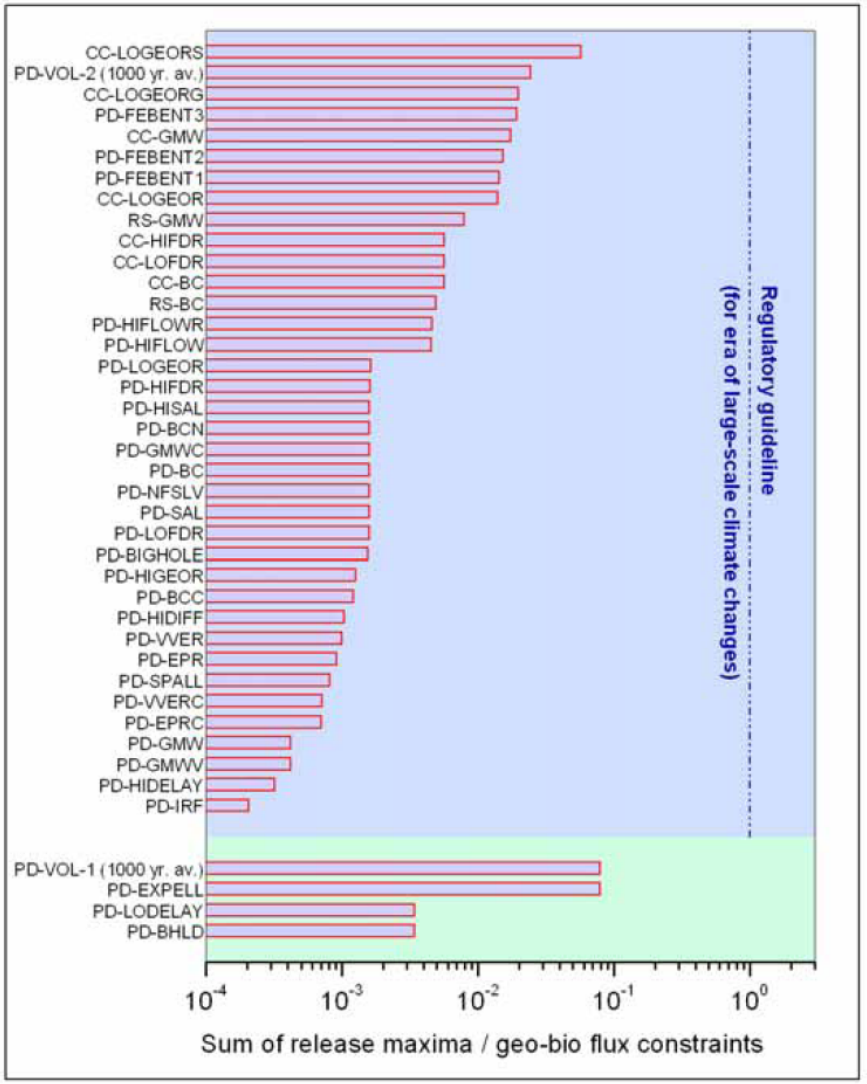
- Activity release based standards:
  - 0.03 GBq/y for long-lived α-emitting Ra, Th, Pa, Pu, Am, and Cm
  - 0.1 GBq/y for Se-79, I-129, and Np-237
  - 0.3 GBq/y for C-14, Cl-36, Cs-135, and the long-lived isotopes of U
  - 3 GBq/y for Tc-99, etc.

    (Based on “reference biosphere” assessments. short-lived progeny are accounted for in parent limits.)
- Nuclear Energy Act and Decree (as amended, 1994)
- Radiation Protection Act (1991)
- Act on Environmental Impact Assessment (1994)

Finland - Safety Assessment

- KBS-3H Safety Assessment (2007)
- Release scenarios normalized to regulatory limits

- Source: Smith, P. et al. 2007. Safety Assessment for a KBS-3H Spent Nuclear Fuel Repository at Olkiluoto: Summary Report. POSIVA 2007-06 (*http://www.posiva.fi/en/search?searchterms=kbs-3h*).

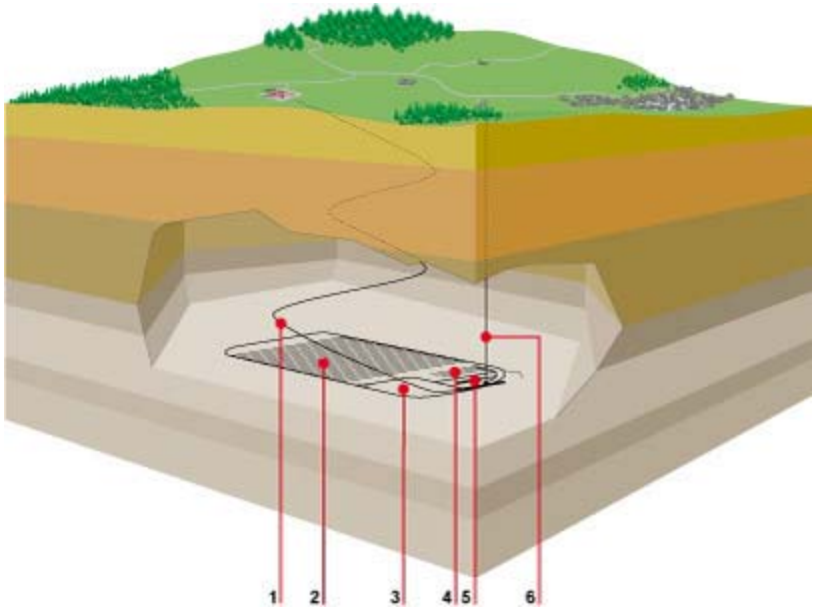


Switzerland - Nuclear Waste Management

- Switzerland: 5 reactors (to be replaced when retired)
- Approximately 4,300 MTHM HLW (spent fuel) considering reactor life extension
- Reprocessed U-Pu MOX (about 1/3 of spent fuel will be reprocessed)
- Reprocessing at La Hague, France and Sellafield, UK
- Waste forms: spent fuel and HLW glass

Switzerland - Characterization and Siting

- **1972** National cooperative (NAGRA) formed
- **1984** Begin investigations at Grimsel Test Facility
- **1996-2008** Investigations at Mont Terri underground laboratory
- **2002** Generic safety assessment for HLW disposal in Opalinus clay
- **2005** Nuclear Energy Act halts reprocessing for 10 years, directs repository program
- **2010** Six locations in Switzerland selected for LLW, ILW, and HLW investigations; discussions with localities to proceed
- **2013** Complete Phase VI at GTS
- **2020** Target for HLW repository operation

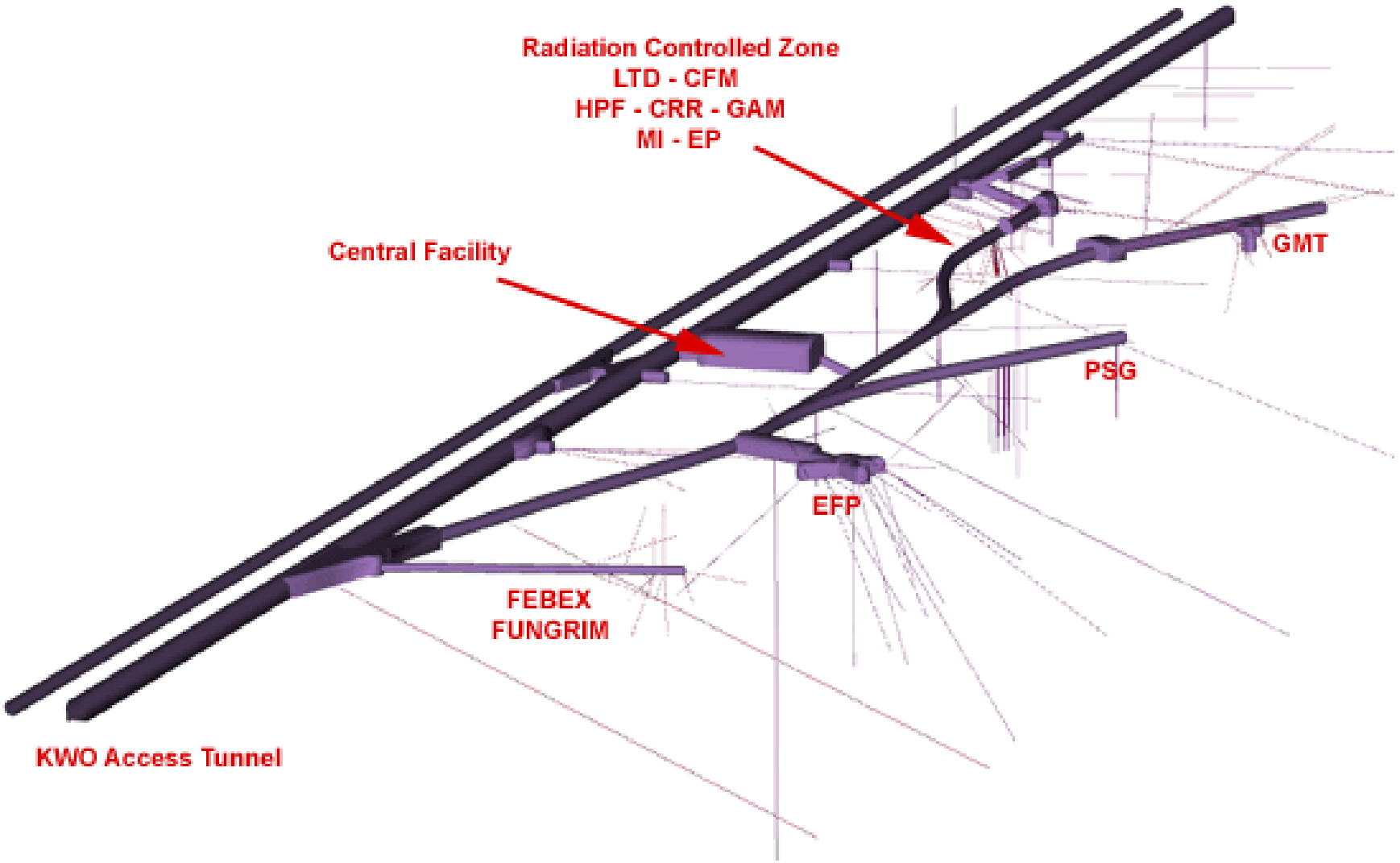


1. Access tunnel
2. Disposal tunnels for spent fuel and vitrified high-level waste
3. Rock laboratory
4. Pilot facility
5. Disposal tunnels for long-lived intermediate-level waste
6. Shaft

Switzerland - Grimsel Test Facility (GTS)

1. Rock laboratory Grimsel
2. Rätherichsbodensee
3. Grimselsee
4. Juchlistock

GTS URL Layout



GTS URL Research

- **Phases I and II (1983 - 1990)**
  - Exploratory boreholes and geological mapping
  - Rock mechanics
    - Excavation effects
    - Rock stress measurements
    - Heater test
  - Geophysical survey techniques
    - High frequency EM measurements
    - Underground seismic
    - Underground radar
- **Phase III (1990 - 1993)**
  - Fracture flow test
  - Tracer migration test
  - Hydrodynamic modeling
  - Unsaturated zone studies
  - Ventilation test
- **Phase IV (1994 - 1996)**
  - Borehole sealing
  - Excavation disturbed zone studies
  - Seismic tomography techniques
  - Two phase flow in fracture network of the tunnel near-field
  - Two phase flow in the matrix of crystalline rocks

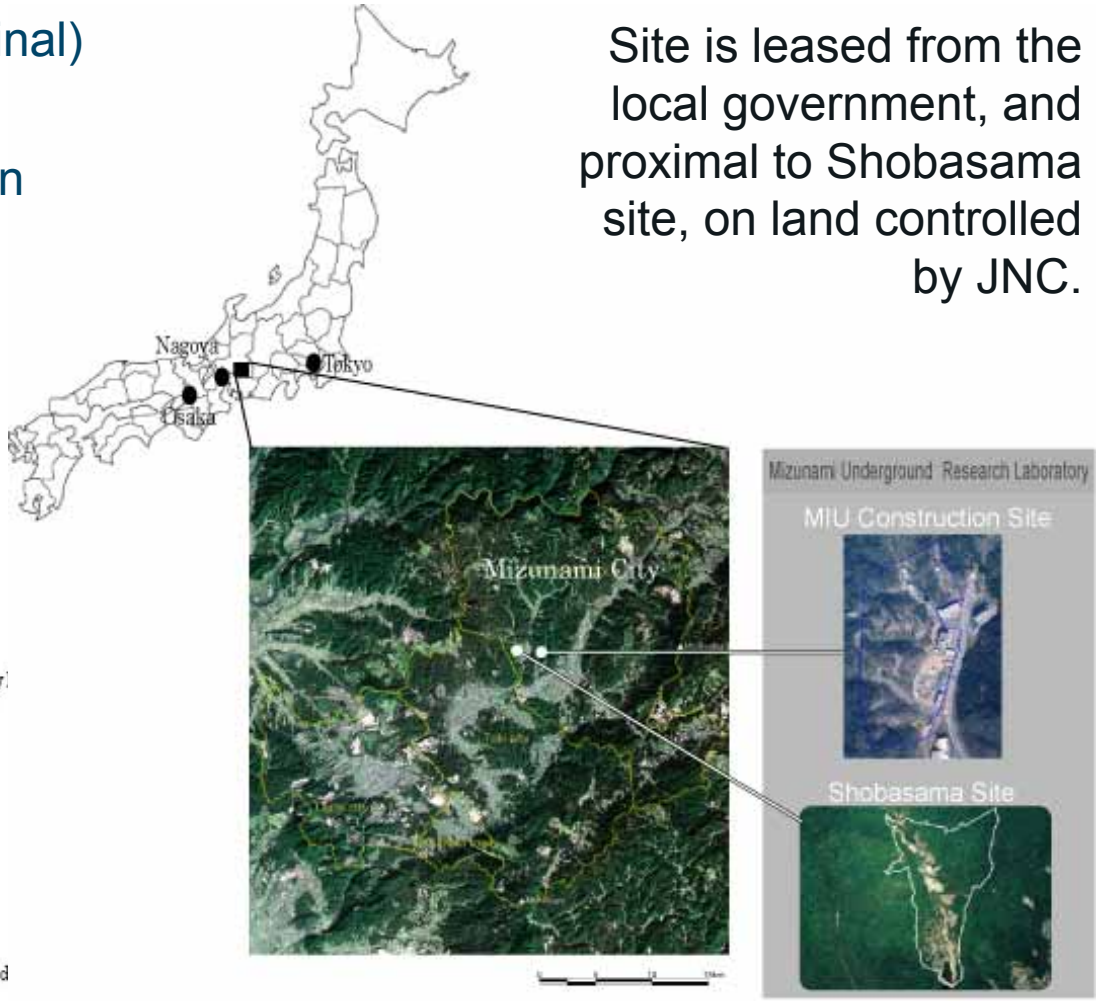
GTS URL Research (Cont.)

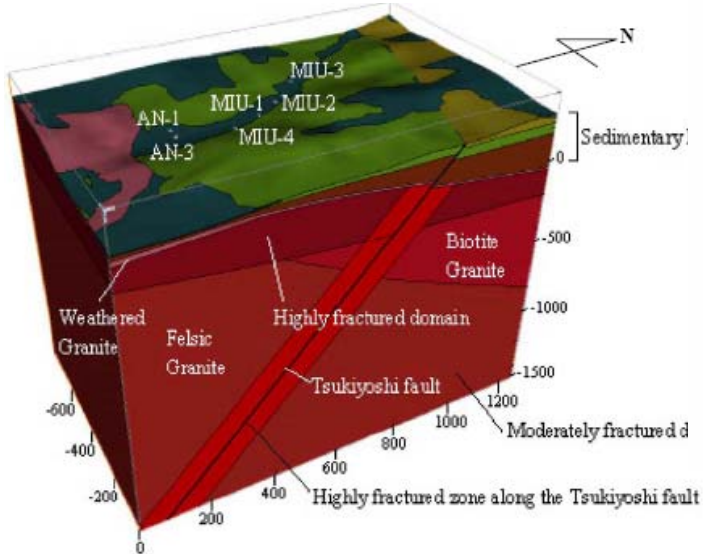
- **Phase V (1996-2004)**
  - **Colloid and radionuclide retardation experiments**
  - Effective field parameters
  - Full-scale HLW engineered barriers experiments
  - Fiber optic monitoring
  - Gas migration in shear zones
  - Gas migration in the engineered barriers
  - Hyperalkaline plume in fractured rocks
- **Phase VI (2003 -)**
  - Pore space geometry
  - Colloid formation and migration
  - **Long-term diffusion**
  - Long-term cement studies
  - Waste handling techniques and equipment
  - Material testing facility

Japan - Mizunami URL

- **May 2010** Shafts at 1000 m (final)
- **2004-2010** Shaft construction
- **2007** Middle stage construction
- **2010-2015** Main stage construction
- **1996-2004** Phase 1 R&D
- **2001-2009** Phase 2
- **2010-2015** Phase 3

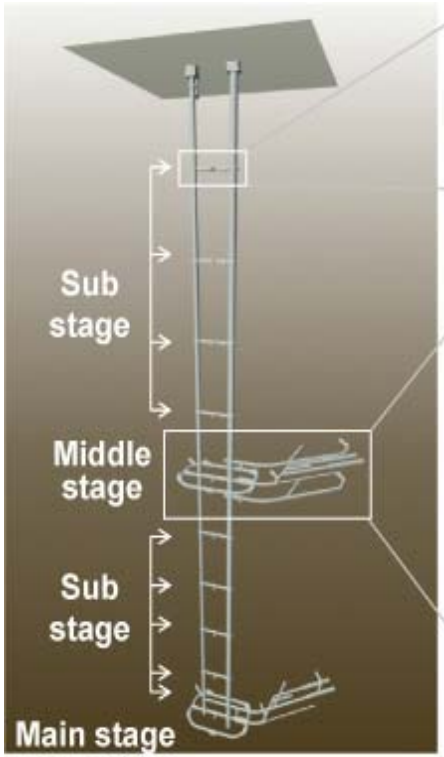
Site is leased from the local government, and proximal to Shobasama site, on land controlled by JNC.



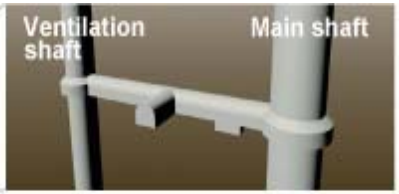


Mizunami - Layout of Underground Facilities

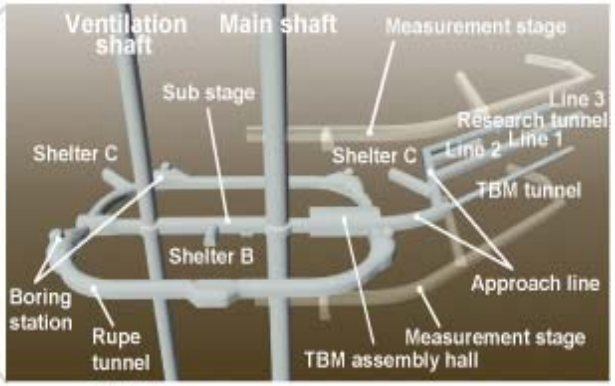
- Compare and reconcile surface-based borehole and underground in situ observations
  - Lithology/petrography
  - Geophysics
  - Flow tests
  - Physical/chemical charater of ground water
  - Rock mechanics



- Maximum depth : 1,025m
- Main stage : depth 1,000m
- Middle stage : depth 500m
- Sub stages : every 100m
- Inner diameter of shaft
  - Main shaft : Φ 6.5m
  - Ventilation shaft : Φ 4.5m



- Sub stages : H3.0m × W3.0m
- Shelter A : H3.0m × W3.0m



- Rupe tunnel : H3.5m × W3.5m
- Approach lin : H3.5m × W3.5m
- Sub stage : H4.0m × W4.0m
- TBM assembly hall : H8.0m × W6.5m
- Shelter B : H3.0m × W3.0m
- Shelter C : H3.5m × W3.5m
- Research tunnel ;
  - Line No.1,3 : H5.0m × W5.0m
  - Line No.2 : H3.5m × W3.5m
- TBM tunnel : : Φ2.2m
- Measurement stage : H3.5m × W3.5m

http://www.jaea.go.jp/jnc/ztounou/miu_e/project/facilities_lay_uf.html

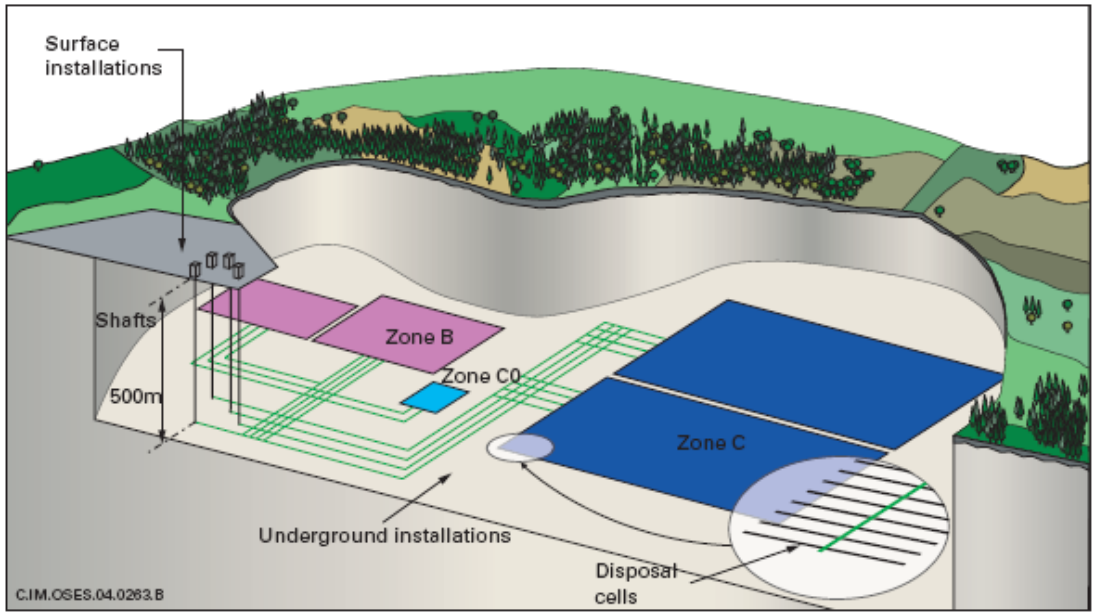
France - Nuclear Waste Management

- France: 59 reactors (plus 2 inoperative sodium-cooled fast reactors)
- In 2030: approximately 5,060 m^3 HLW glass (plus 74 m^3 spent fuel) in pour canisters containing ~0.15 m^3 each.
- "Dossier 2005" disposal concept (argillite)
- Multiple-recycle U-Pu MOX fuel cycle
  - 30% of output is currently from reprocessed fuel
  - Additional reprocessing facilities and greater throughput capacities are planned
  - Extensive spent fuel storage (pools, dry-cask)
  - Fast-reactor transmutation demonstration targeted for 2020

France - Characterization and Siting

- **1991**(2006) Waste Management Act
- **1993** Callovo-Oxfordian argillite (Bure locality)
- **1994-1996** Surface investigations at Meuse/ Haute-Marne and other localities
- **1998** Meuse/Haute-Marne URL created to study Callovo-Oxfordian formation
- **1999-2005** URL construction

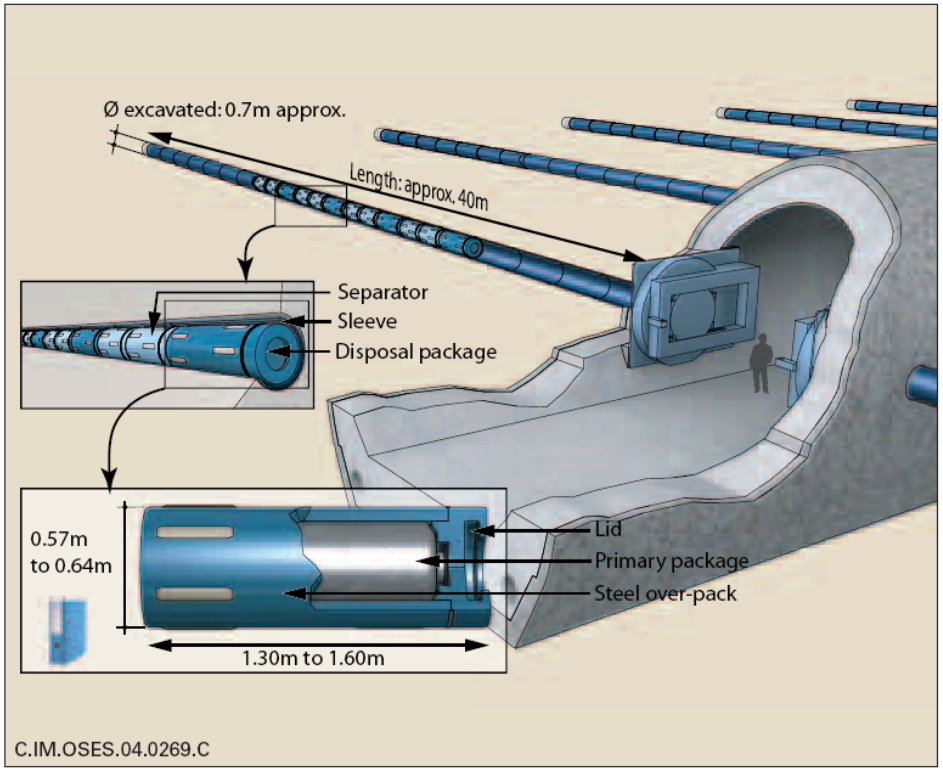
Conceptual View of a Repository in Operation - Phased Disposal Zones



- **2005** "Dossier 2005" report on feasibility of permanent geologic disposal
- **2006** Nuclear Materials and Waste Management Program Act (15 years)
- **2010** ANDRA receives government approval to site repository within 200 km^2 "transposition" zone
- **2015** Target date for licensing a repository
- **2025** Target date for repository operation

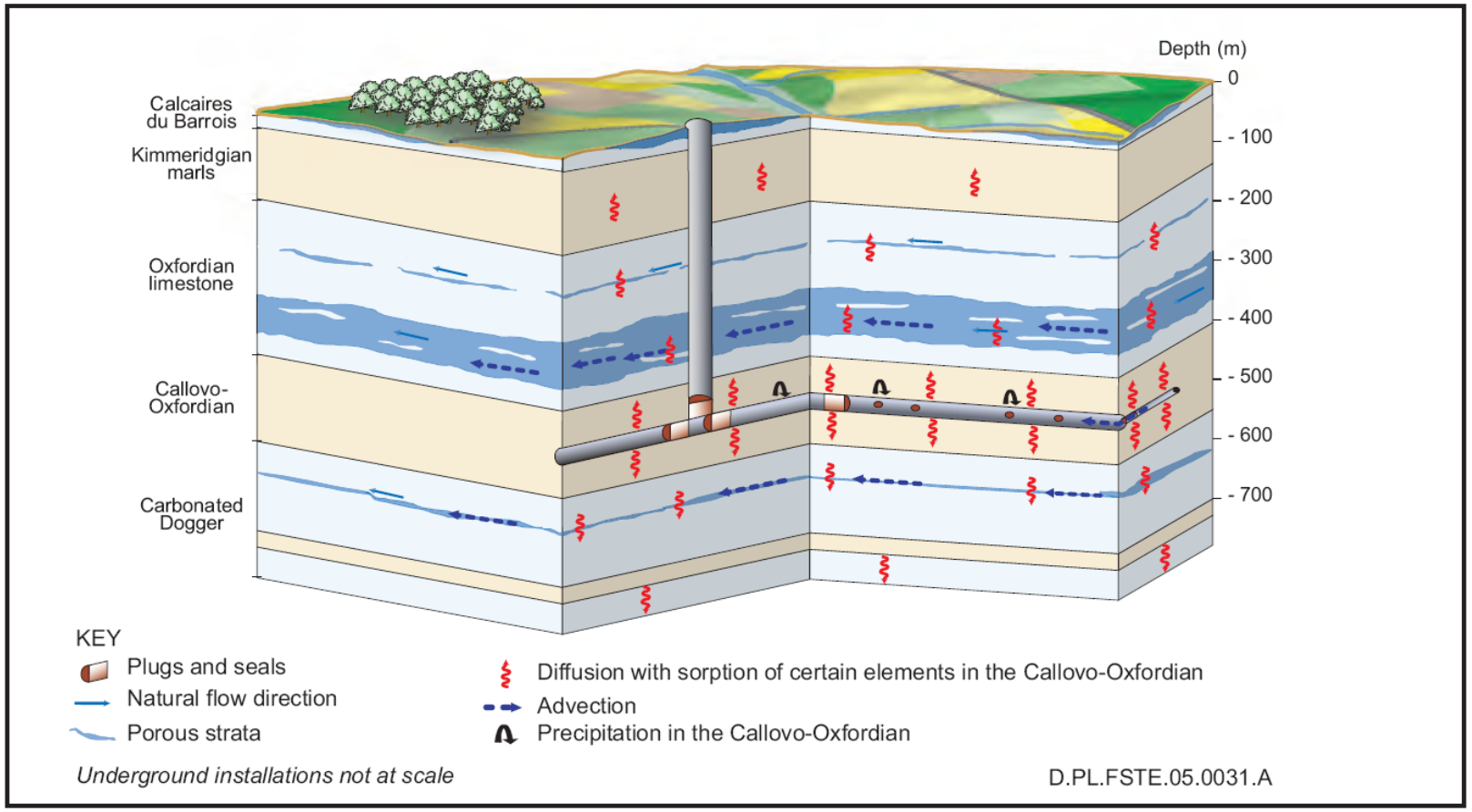
Reference Concept for HLW Disposal in Clay/Shale Media

- Horizontal emplacement
- Limited engineered barriers
  - Stainless steel pour canister
  - Single-canister overpack
  - Clay-based borehole seals
  - Access drift backfill
  - Zone and shaft seals
- Waste isolation strategy
  - Low permeability host rock
  - Re-sealing fractures in EDZ
  - Chemically reducing conditions inhibit oxidative degradation, and radionuclide solubility (pyrite, natural organic matter in host clay)
  - Limited sources of groundwater inflow/outflow



France: Dossier 2005 Performance Assessment

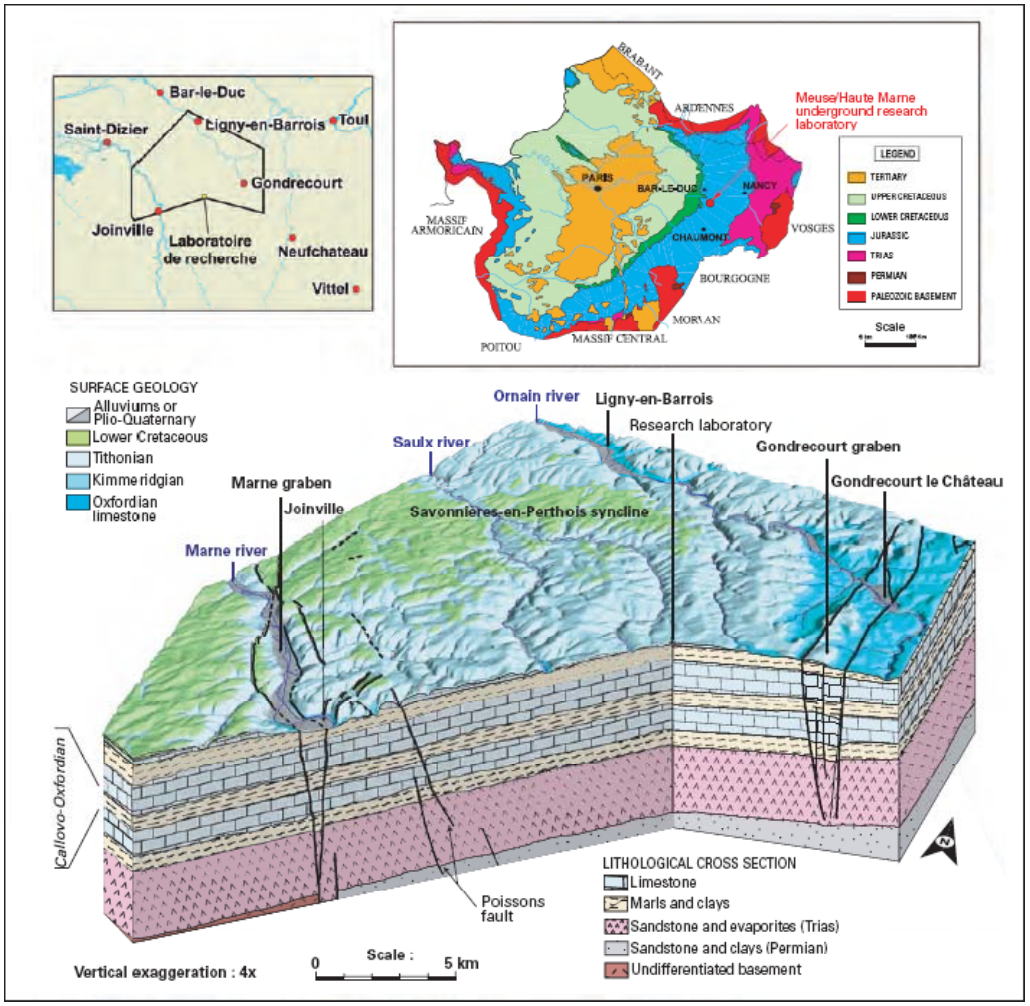
Processes Affecting Waste Radionuclide Fate and Transport



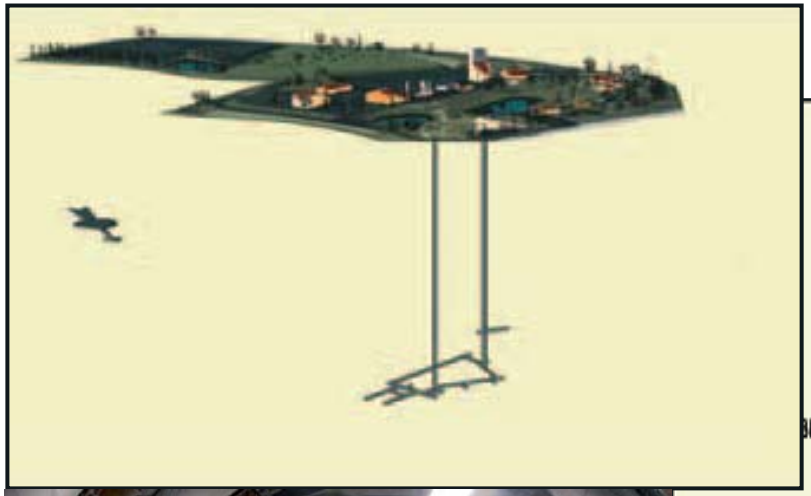
Source: ANDRA Dossier 2005 Argile Synthesis

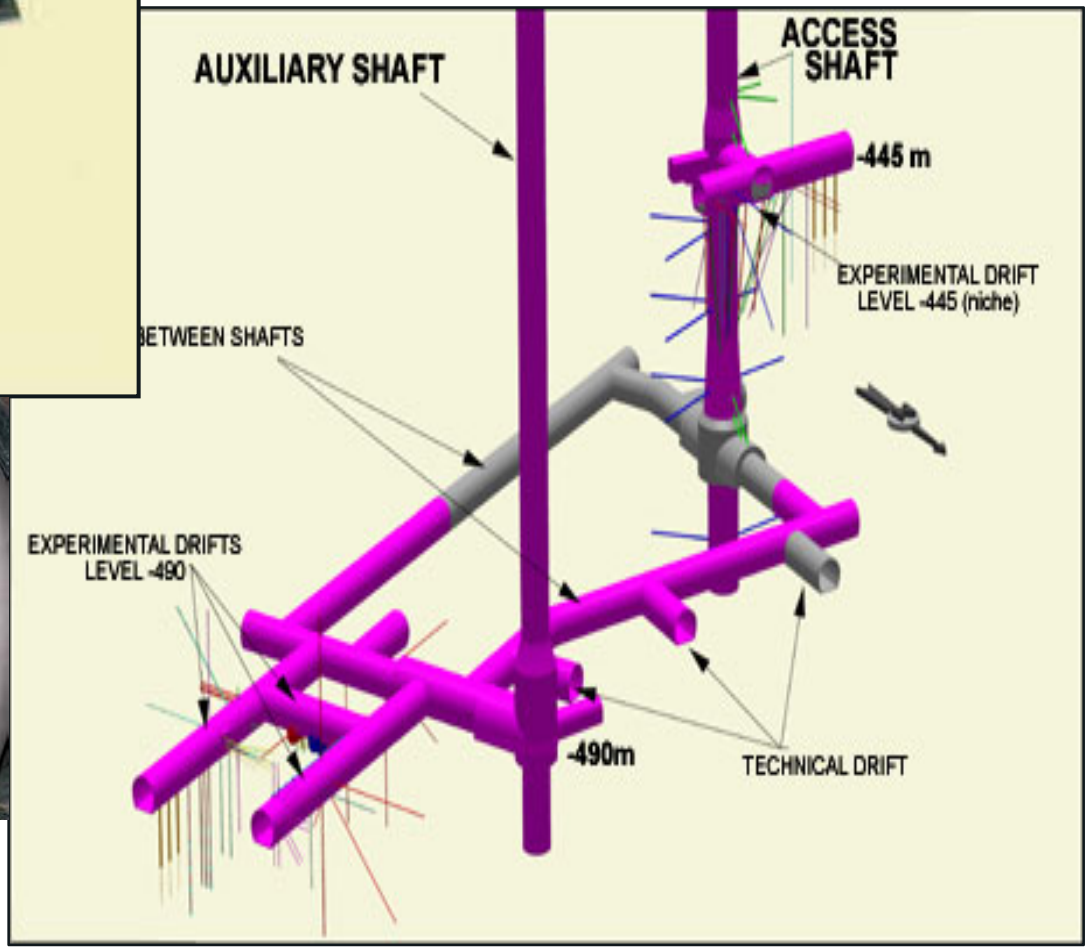
Meuse/Haute-Marne URL (Bure, France)

- Study conditions for HLW disposal in argillite
- Slightly dipping (~1° NW) Paris Basin sediments
- 155 Myr age
- Sequence of limestone, clay, marl, sandstone, evaporites



Meuse/Haute-Marne URL Layout





Meuse/Haute-Marne URL Research

- **Surface-Based Studies**
  - Borehole measurement of mechanical properties, permeability, and diffusion properties
  - 2D and 3D geophysical surveys
  - Hydrogeological monitoring
  - Seismic (earthquake) monitoring network
- **Underground Studies During Shaft Sinking**
  - Detailed geology
  - Water collection and flow-rate measurements in overlying strata
  - Monitoring rock mechanical behavior including EDZ
- **Underground Studies at -500 m**
  - Permeability and radionuclide diffusion measurements
  - Investigation of rock mechanical behavior including EDZ
  - Monitoring of pore water chemistry
  - Performance tests on grooves filled with swelling clay
  - Thermal conductivity measurements
  - Heater tests for coupled THM response
  - Large diameter borings

France - Geologic Repository Regulatory Context

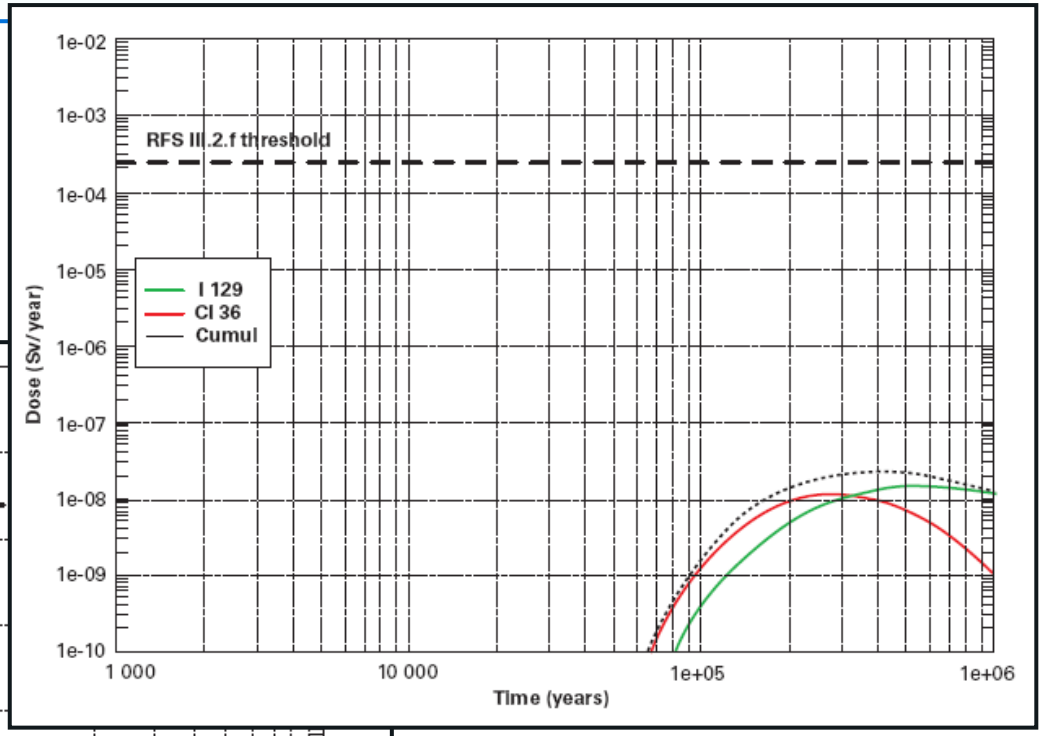
Final repository dose-based standards:

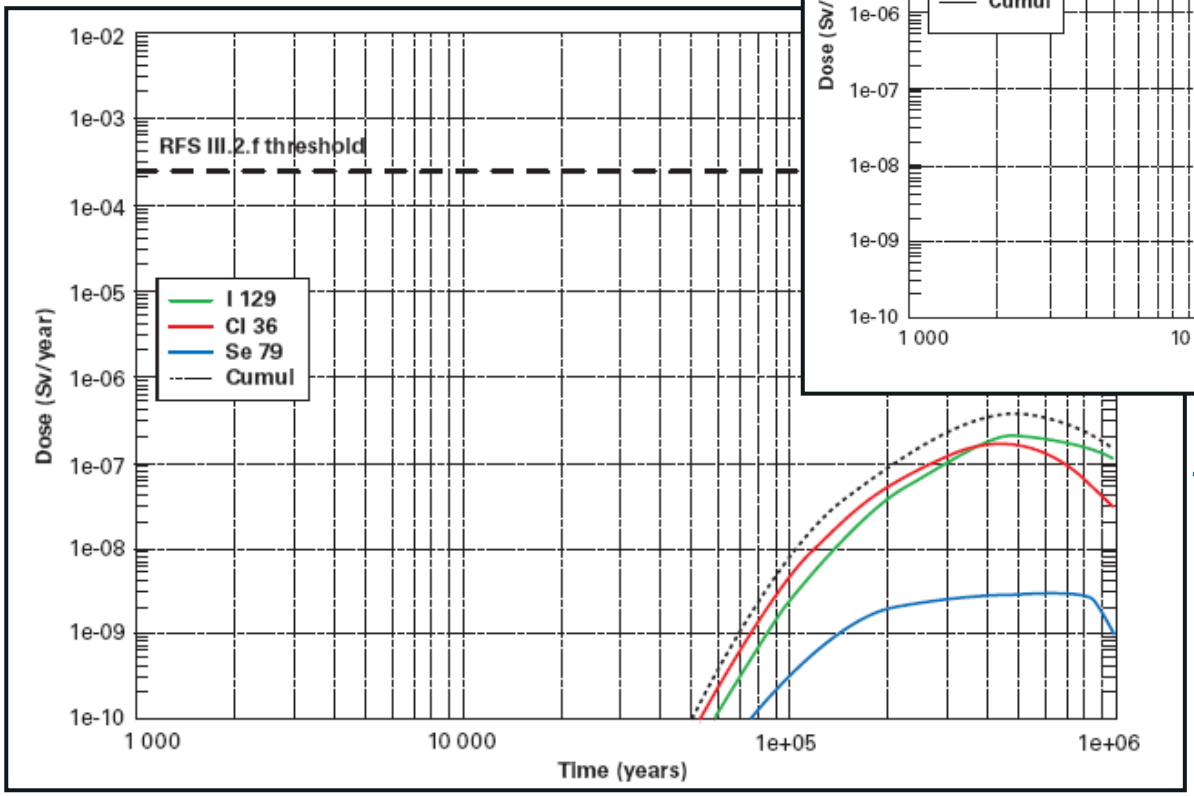
- RFS III.2.f Safety Rule (issued 1991)
  - Impact of a repository to a level **as low as reasonably achievable**
  - Individual long-term dose limit: **0.25 mSv/yr** (normal conditions)
  - Necessitates a **multi-barrier** disposal concept, i.e., waste packages, the engineered barrier, and the geological medium itself.
  - Major expectations with respect to a potential site:
    - Long-term geodynamic stability (esp. no significant earthquake risk)
    - No important water circulation in the geological medium
    - Adequate mechanical properties of the rocks to allow excavation
    - Radionuclide isolation properties of the geological medium
    - Sufficient depth
    - No exploitable outstanding natural resources in the vicinity

France: Dossier 2005 Performance Assessment

Worst case outlet (Saulx River).
Scenario S1b (single-recycle MOX);
42,300 MTHM reprocessed.

Reference Bitumized Waste
(Type B packages) >>>





<<< Reference HLW glass
(Type C1+C2 packages)

Source: ANDRA Dossier 2005
Argile Synthesis

France: Important FEPs in Clay Repository Assessment

- **Relatively significant processes**
  - Robust radionuclide attenuation processes (radioactive decay, precipitation, sorption)
- **Insignificant processes**
  - Thermal effects
  - Early container failure
  - Colloidal transport
  - Non-performing seals
- **Important uncertainties**
  - Transport along repository drifts and EDZ
  - Effectiveness of plugs and seals, “dead-end” repository architecture
  - Advective-diffusive (Peclet) transport along intersecting discontinuities (if any)

Switzerland - Nuclear Waste Management

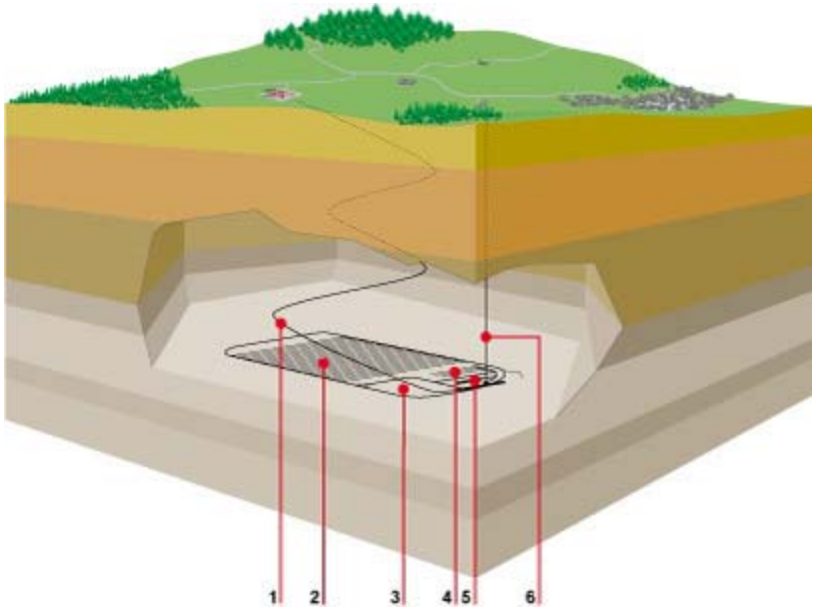
(previous slide)

- Switzerland: 5 reactors (to be replaced when retired)
- Approximately 4,300 MTHM HLW (spent fuel) considering reactor life extension
- Reprocessed U-Pu MOX (about 1/3 of spent fuel will be reprocessed)
- Reprocessing at La Hague, France and Sellafield, UK
- Waste forms: spent fuel and HLW glass

Switzerland - Characterization and Siting

(previous slide)

- **1972** National cooperative (NAGRA) formed
- **1984** Begin investigations at Grimsel Test Facility
- **1996-2008** Investigations at Mont Terri underground laboratory
- **2002** Generic safety assessment for HLW disposal in Opalinus clay
- **2005** Nuclear Energy Act halts reprocessing for 10 years, directs repository program
- **2010** Six locations in Switzerland selected for LLW, ILW, and HLW investigations; discussions with localities to proceed
- **2013** Complete Phase VI at GTS
- **2020** Target for HLW repository operation

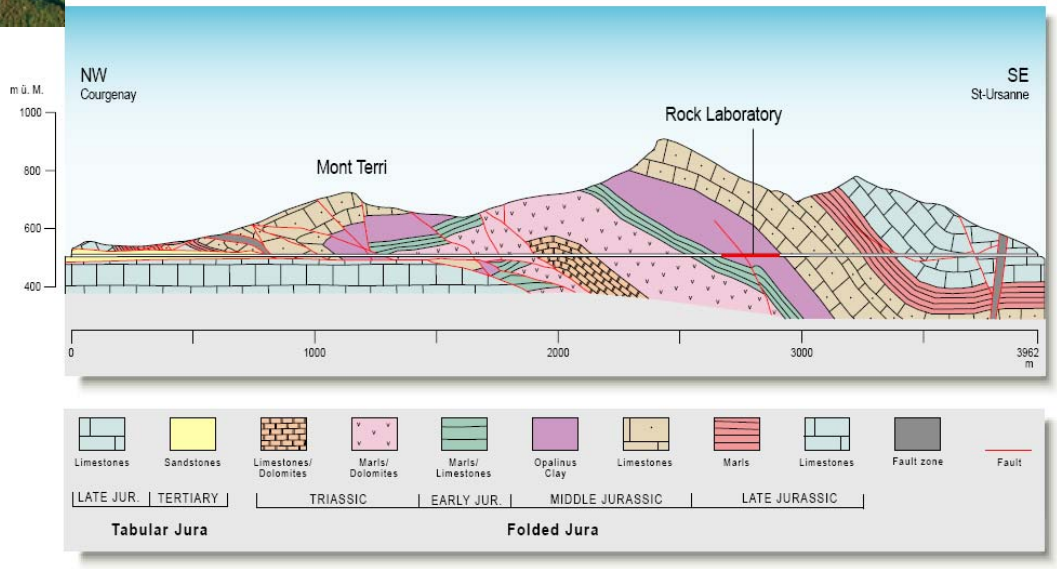


1. Access tunnel
2. Disposal tunnels for spent fuel and vitrified high-level waste
3. Rock laboratory
4. Pilot facility
5. Disposal tunnels for long-lived intermediate-level waste
6. Shaft

Mont Terri Rock Laboratory (Switzerland)

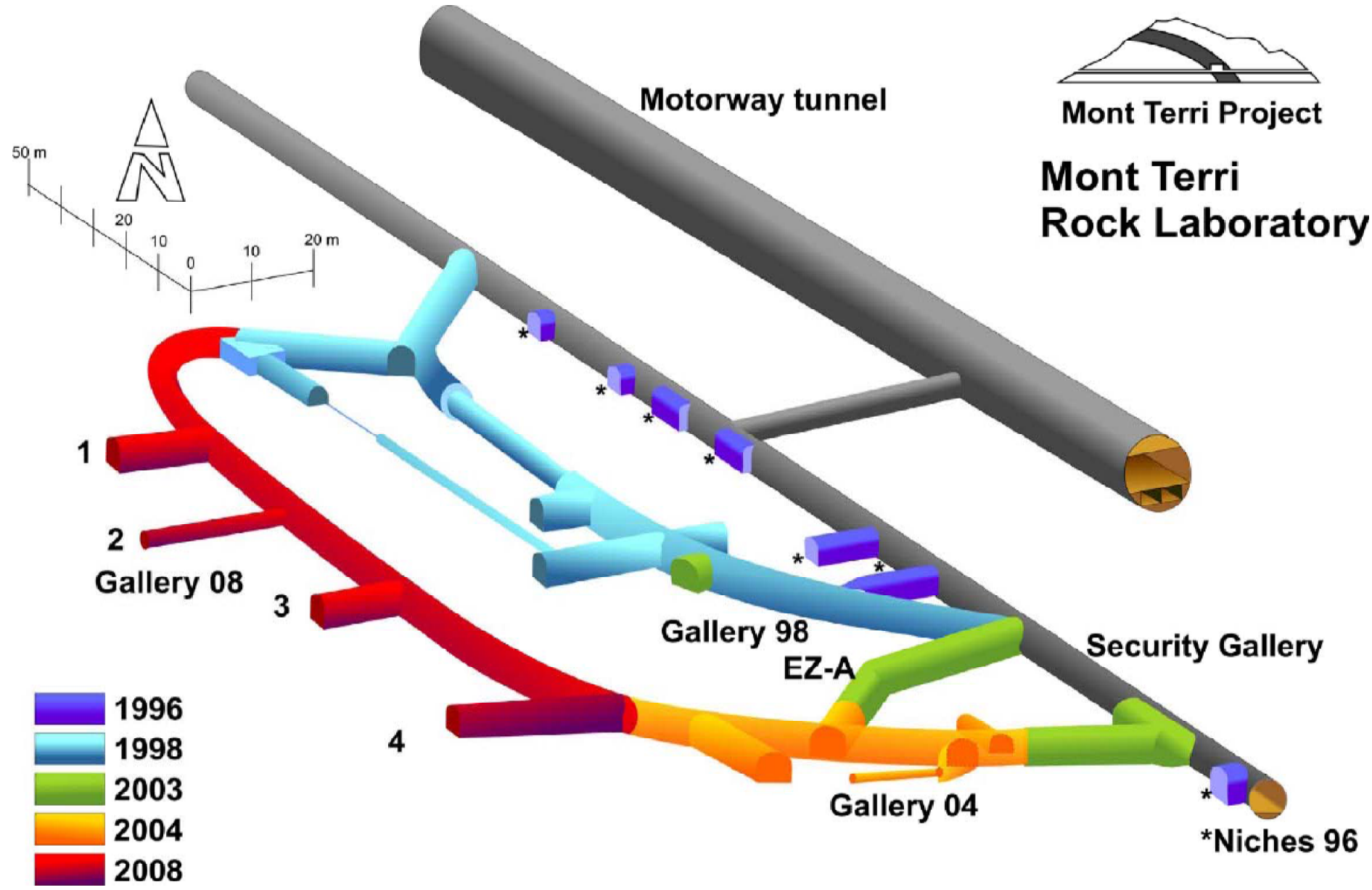
- Project timeline
  - **1989** Excavation of reconnaissance gallery from motorway tunnel.
  - **1996** Mont Terri rock laboratory construction initiated
  - **1996-present** International collaborations/experiments

- Project Opalinus Clay
- Investigate clay lithology
- Simpler geologic structure to the west (tabular Jura)



Michael Freivogel (2001, University of Basel)

Mont Terri URL Layout



Mont Terri URL Research Program

- **Characterization of Opalinus Clay**
  - Fluid/gas advective transport properties
  - Diffusion properties
  - Geomechanical stress conditions and deformability
  - Geochemical properties (pore water, sorption)
- **Investigate excavation disturbed zone (EDZ)**
  - Evolution of EDZ (formation of fractures, changes in pore water pressure, hydraulic conductivities, stress distribution, chemistry, mineralogy)
  - Thermal-hydrologic-mechanical coupling
- **Evaluate characterization methods**
  - Pore pressure
  - Pore water sampling
  - Hydraulic and gas permeability testing
  - EDZ characterization
  - Stress and deformation measurements
  - Advective and diffusive transport studies
- **Repository engineering demonstrations**

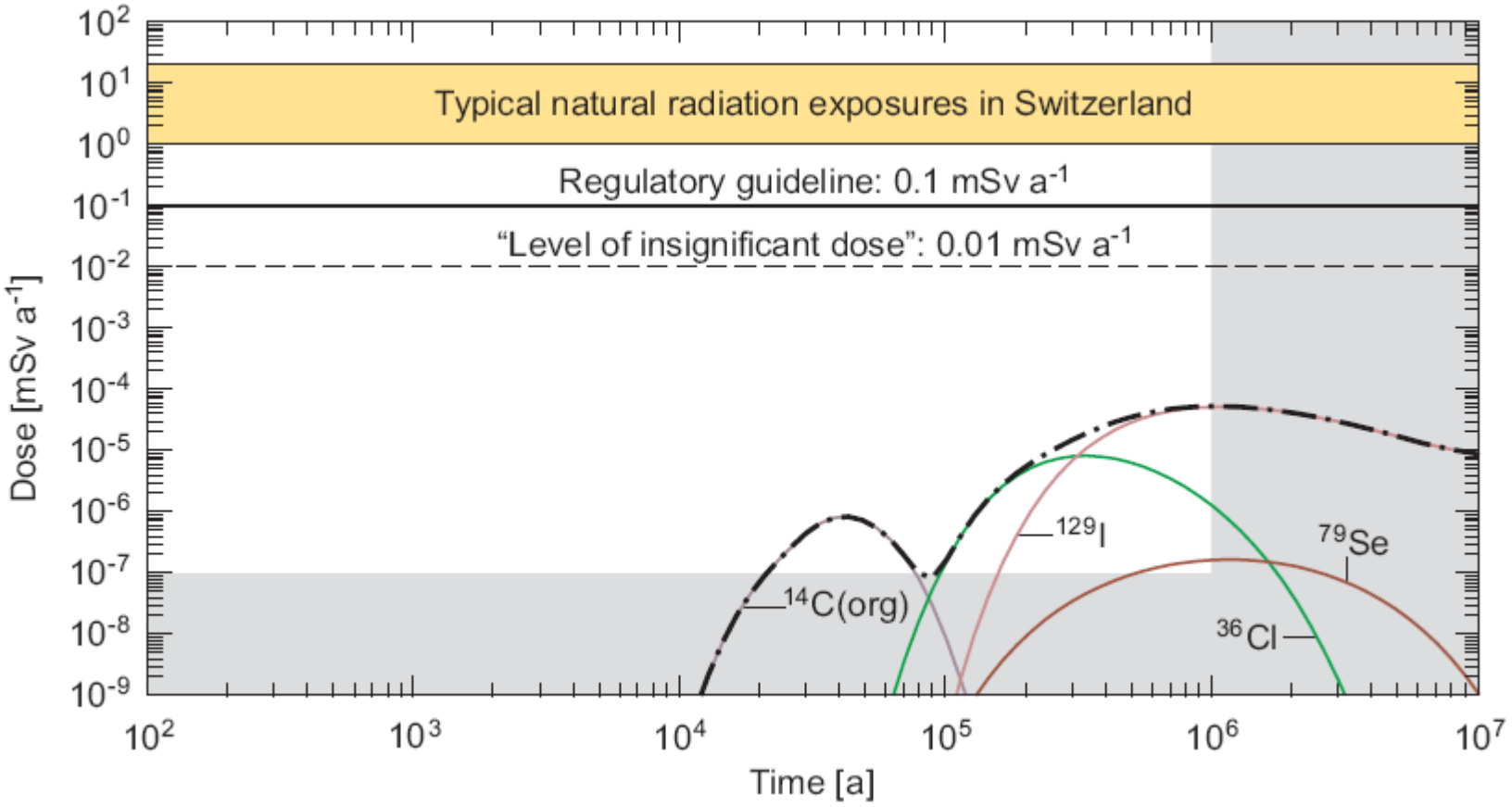
Switzerland- Geologic Repository Regulatory Context

Guideline ENSI-G03: Protection Objectives for the Disposal of Radioactive Waste

- Individual Radiological Protection
  - Dose limit: 0.1 mSv/yr
  - Performance for “less likely” conditions (e.g., disturbed, must be defined) : risk of fatality < 10^{-6}/yr
- Risks may not be greater in other countries than are permissible in Switzerland
- Staged, passively functioning (multiple) natural and engineered barriers
- Future use of natural resources must not be unnecessarily restricted by the presence of a repository
- Biodiversity may not be put at risk by geological disposal.
- Alternatives are to be considered with a view to **optimising** operational and long-term safety

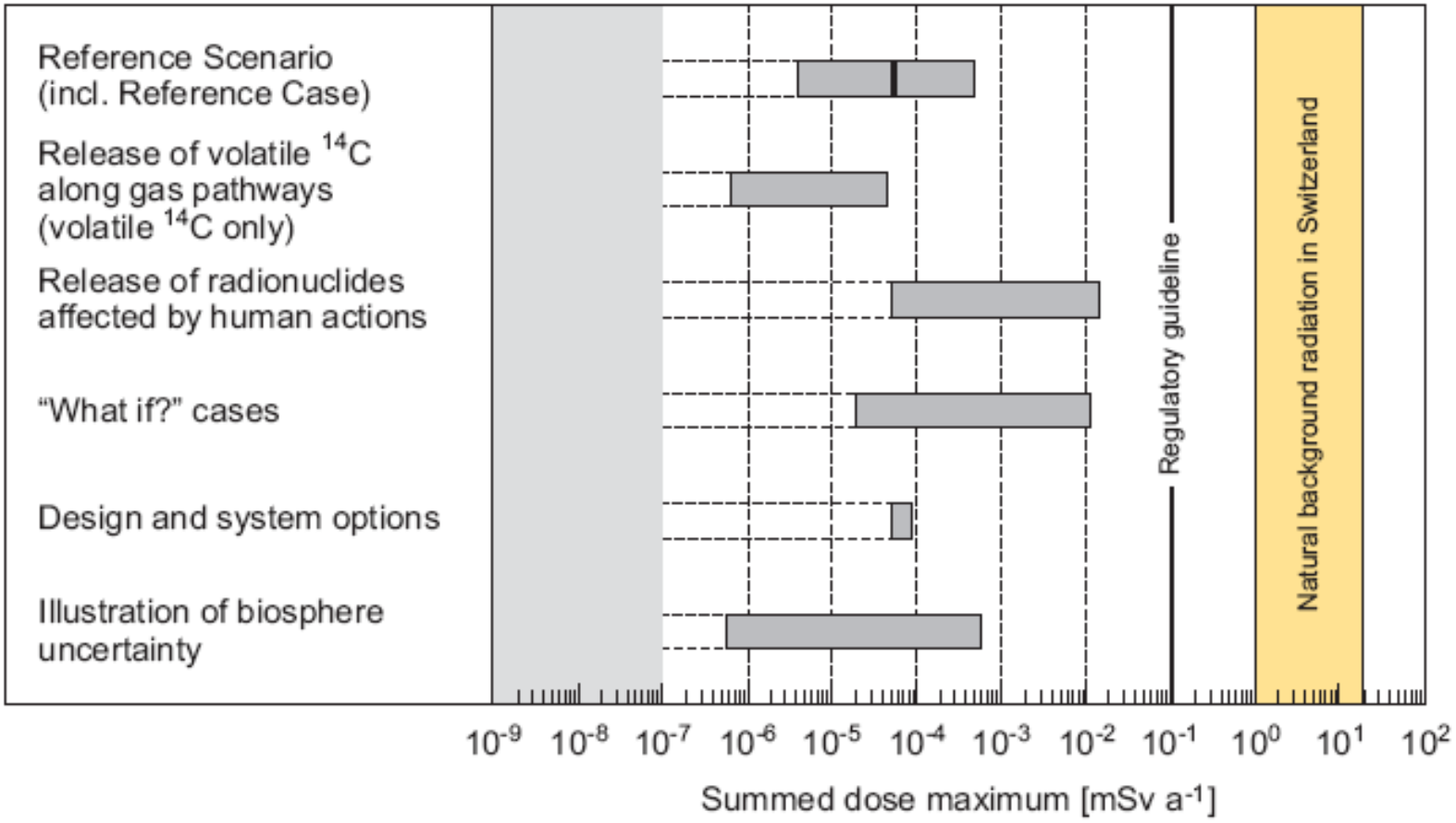
Switzerland: 2002 Performance Assessment

Generic assessment, nominal scenario, combining ILW, HLW, spent fuel.



Source: NAGRA NTB 02-05 Project Opalinus Clay

Switzerland: Important FEPs in Clay Repository Assessment



Source: NAGRA NTB 02-05 Project Opalinus Clay

Belgium - Nuclear Waste Management

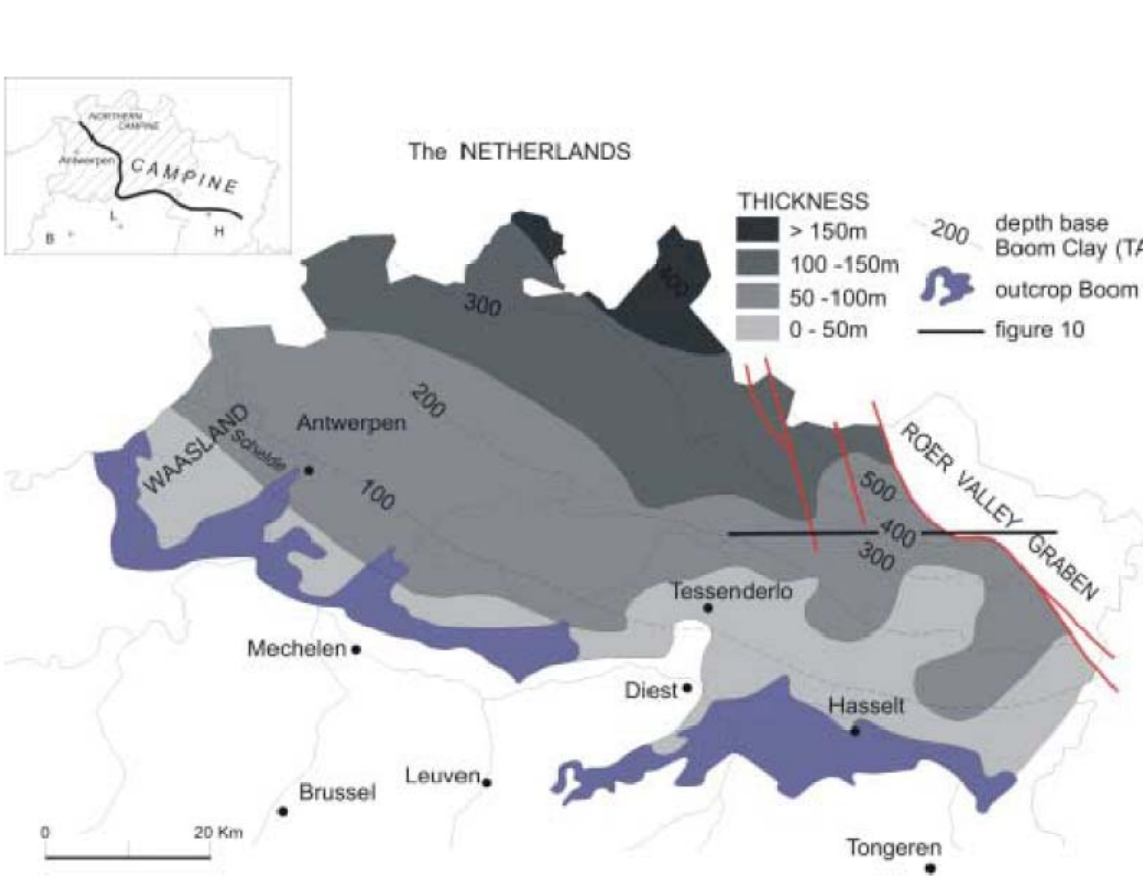
- Belgium: 5 reactors (to be replaced when retired)
- Approximately 4,300 MTHM HLW (spent fuel) considering reactor life extension
- Reprocessed U-Pu MOX (about 1/3 of spent fuel will be reprocessed)
- Reprocessing at La Hague, France and Sellafield, UK
- Waste forms: spent fuel and HLW glass

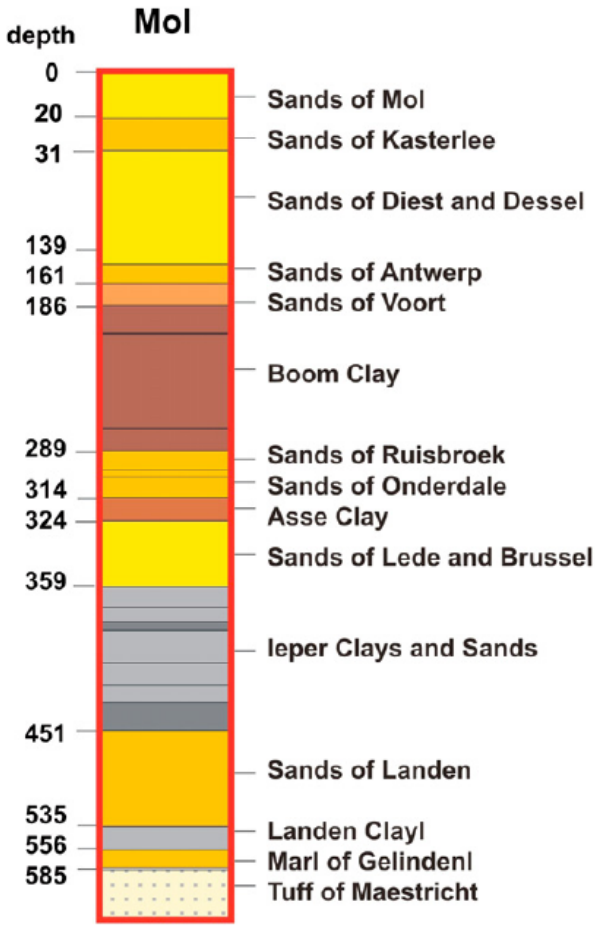
Belgium - Characterization and Siting

Belgium: High-Activity Disposal Experiment Site (HADES) URL

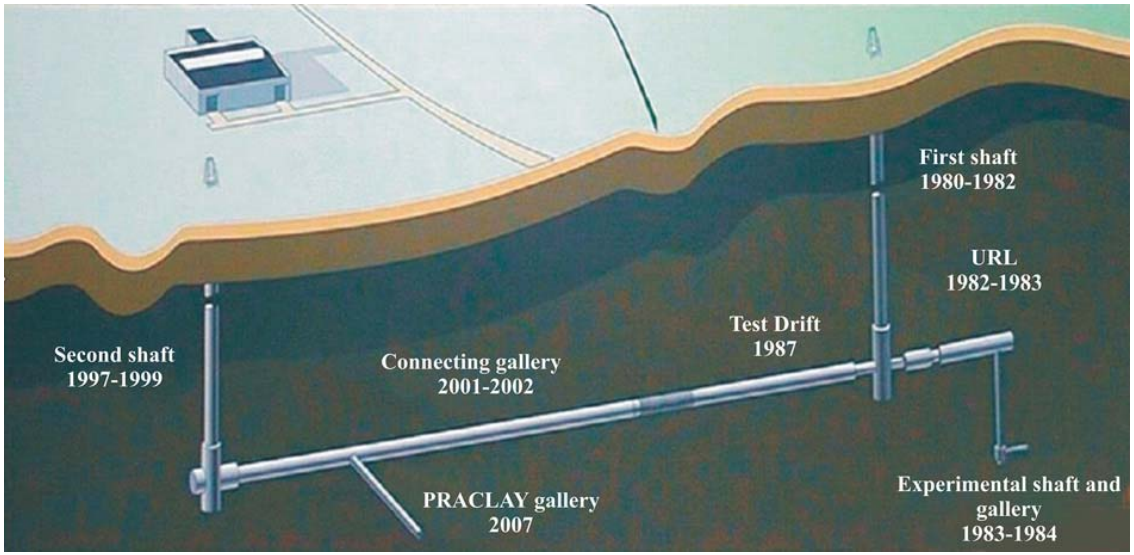
- Study radioactive waste disposal in Boom Clay Formation
- Project timeline
  - 1952 - Belgian Nuclear Research Center (SCK-CEN) established
  - 1974 - SCK-CEN begins study of Boom Clay formation beneath Mol-Dessel nuclear zone
  - 1980 - Belgian Agency for Radioactive Waste and Fissile Materials (ONDRAF/NIRAS) established
  - 1980 -1987 Construction of HADES URL
  - 1989 - Safety Assessment and Interim Feasibility Report (SAFIR)
  - 2003 - SAFIR2 report

Boom Clay Formation





HADES Underground Research Facility (Mol)



- Plastic Boom Clay
- Thickness ~100 m
- URL depth ~ 225 m
- 30 Myr geologic age
- Hydraulic conductivity ($k \sim 10^{-12}$ m/s)
- Anisotropy ($k_h \sim 2 \times k_v$)
- 25% water content
- 1 to 5% organic matter

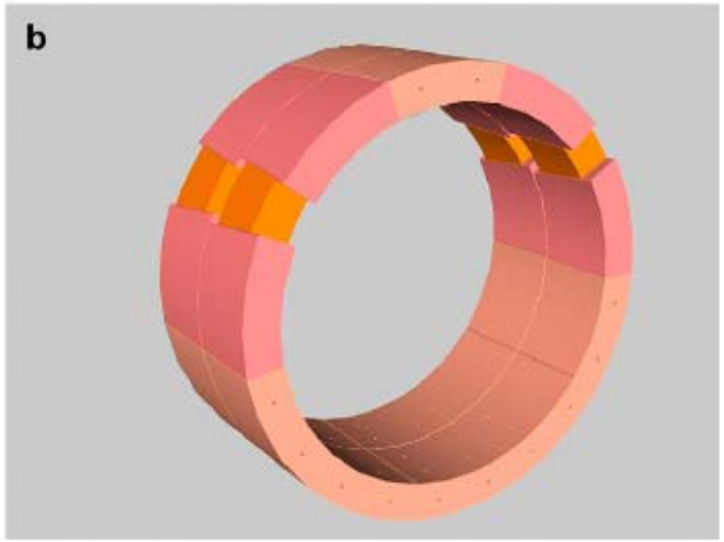
Summary of URL Investigations

- Identify/characterize discontinuities (fractures, faults) and lithologic heterogeneity, of the Boom Clay
- Measure the effects from discontinuities and heterogeneities on the migration of radionuclides
- Characterize coupled thermo-hydro-mechanical behavior in response to excavation and heating
- Support modeling of regional and local hydrogeology

HADES URL - Boom Clay

Photos from HADES URL, Boom Clay

Source: van Marcke & Bastiens 2010. *J. Struct. Geol.* 1-8.



(above)

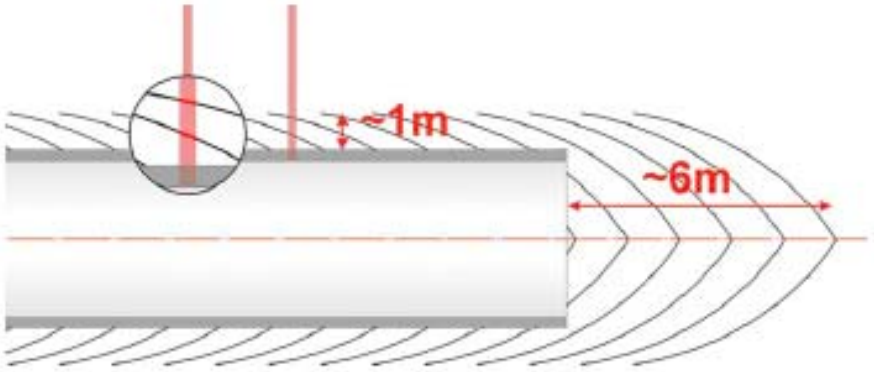
Fully shielded tunnel boring machine, road header

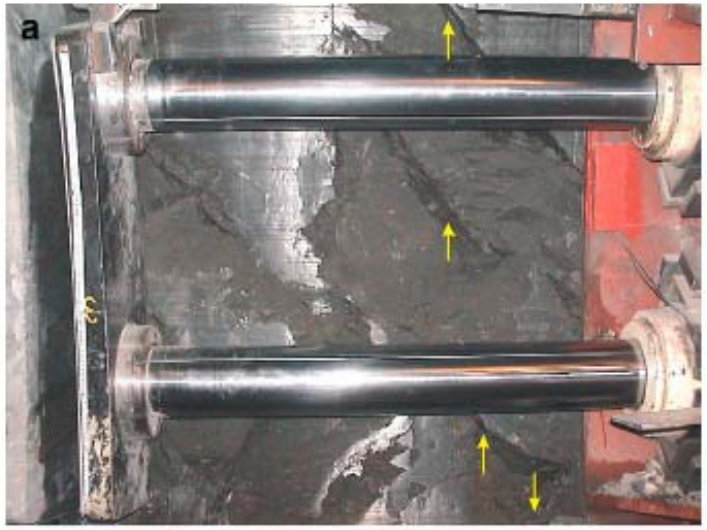
(right)

(a) Completed Connecting Gallery

(b) Pre-cast concrete liner schematic

HADES URL - Boom Clay





Excavation Induced Fracturing, Boom Clay

(above)
Conjugate fracture pattern
(a) Fractures observed in tunnel wall.
(b) Fractures observed on excavation face.

Source: van Marcke & Bastiens 2010. *J. Struct. Geol.* 1-8.

International Development in Clay and Crystalline Rock

Summary

- Repository development in crystalline rock
  - Sweden, Finland plan pilot-scale repository operations in 2015-2020 time frame
  - Engineered barrier strategies emphasizing clay buffer behaviors
- Repository development in clay/shale media
  - France plans pilot-scale repository operations in 2020 time frame
  - Natural barrier strategy emphasizing diffusion dominated transport
- Strong international collaborations
- Siting methods have changed since mid-1990s
- Important differences in long-term safety criteria

International Development in Clay and Crystalline Rock

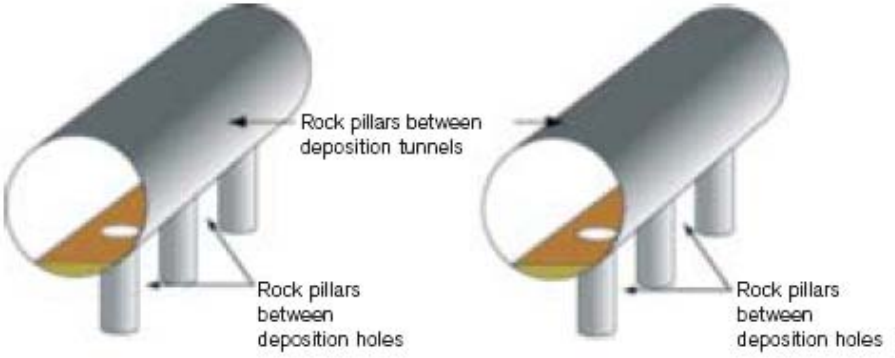
"Lessons Learned"

- Voluntary siting
  - Programs in Sweden, Finland, France, and Switzerland have adapted to political constraints
- Public access to all information (Internet)
- Flexible safety regulations
  - Dose vs. release criteria
  - Normal vs. "less likely" or disturbed conditions
  - Retain flexibility as program advances
- Phased development
  - URLs, then pilot-scale repository facilities are proposed
  - Organization size should be appropriate for each phase
  - Use international collaboration to control costs

Backup Slides

Äspö URL Research (Cont.)

- Rock Mechanics
  - Zone of excavation disturbance experiment (ZEDEX)
  - Pillar stability experiment



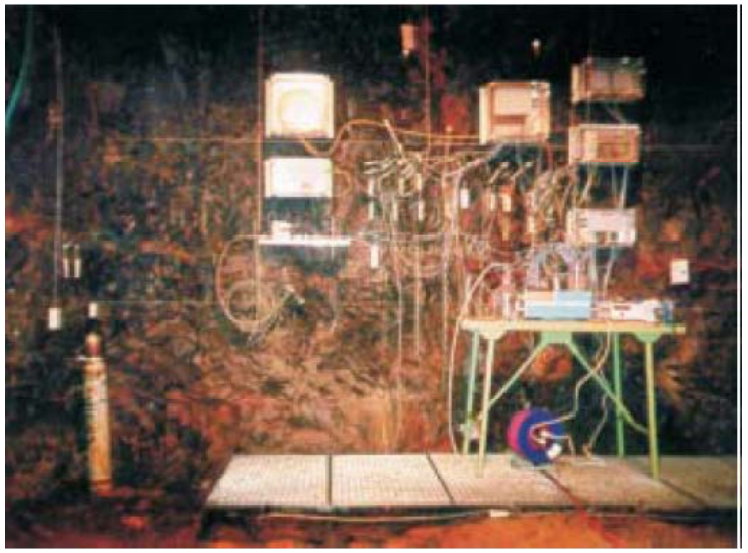
The fractures around the tunnel were a few centimetres deep.

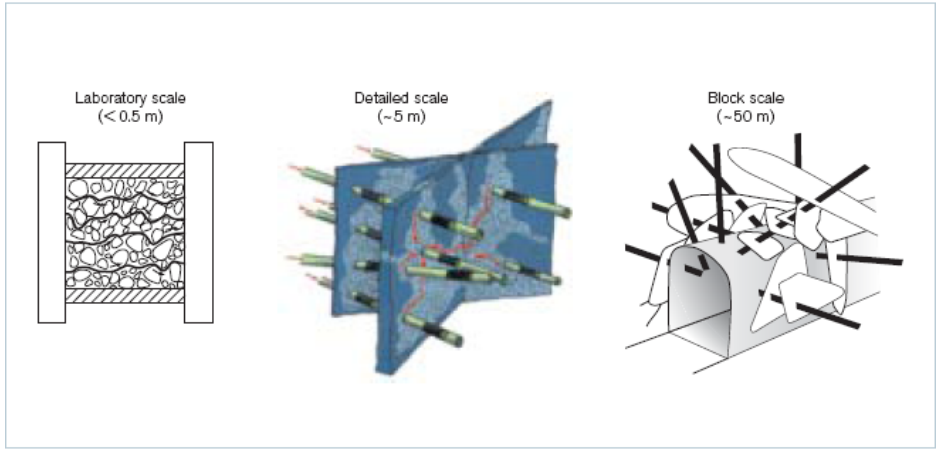
The fractures around a drilled-and-blasted tunnel are much deeper. They were around 30 centimetres in the walls.

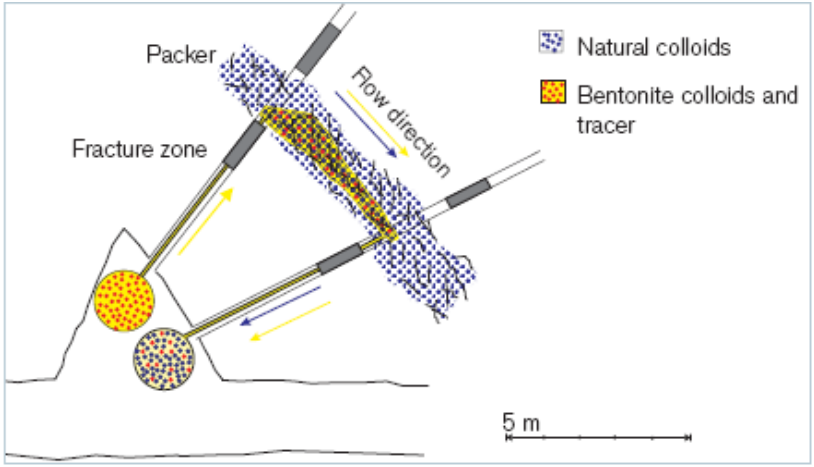
Fractured rock mass in rock pillar.

Äspö URL Research

- Groundwater Flow and Radionuclide Transport
  - Two-phase flow project
  - Colloid project
  - Radionuclide retention experiment (RNR)
  - Tracer retention understanding experiments (TRUE)
  - Long-term diffusion experiment (LTDE)
  - Matrix fluid chemistry experiment
  - Redox experiment in detailed scale (Rex)
  - Microbe project

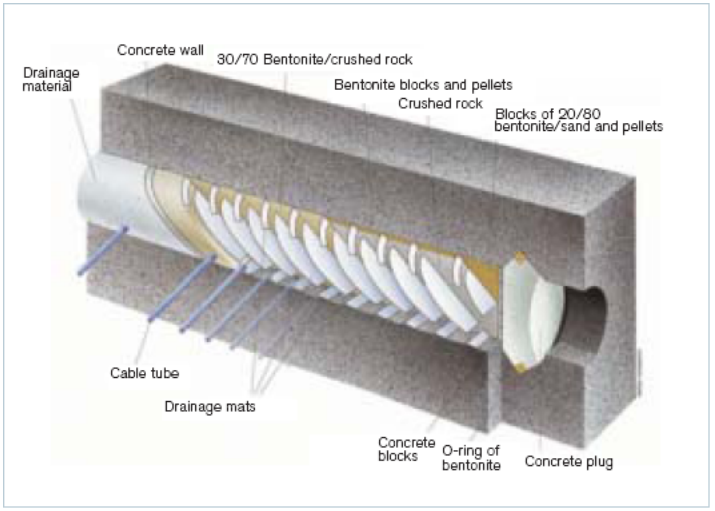


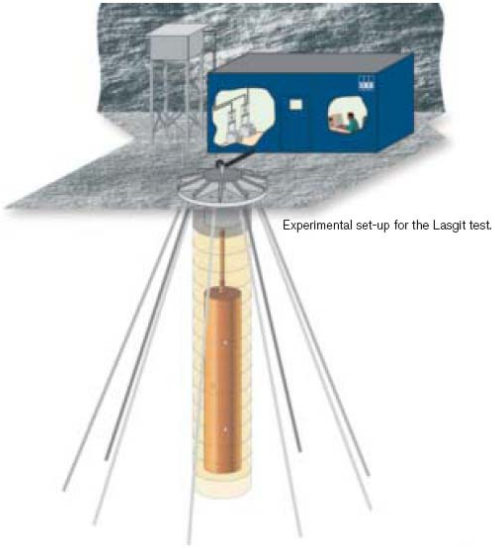




Äspö URL Research (Cont.)

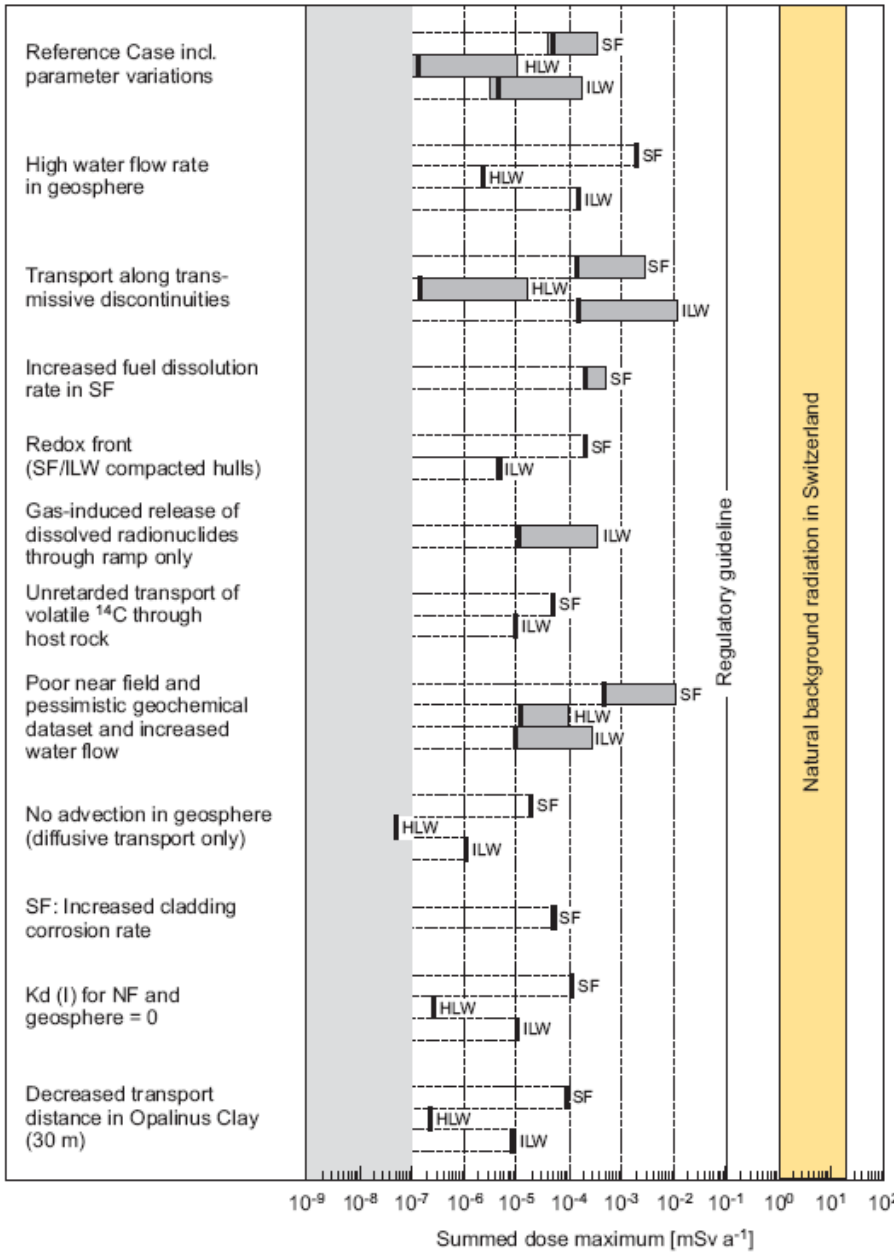
- Engineered Barriers
  - Backfill and plugging test
  - Long-Term test of buffer materials (LOT)
  - Temperature buffer test
  - Large-scale gas injection test (Lasgit)





URLs in Sedimentary Rock

- France
  - Meuse/Haute Marne (Callovo-Oxfordian argillite)
  - Amelie (salt)
  - Tournemire (clay)
- Switzerland
  - Mont Terri (Opalinus claystone)
- Belgium
  - HADES (clay)
- Hungary
  - Pécs (shale)
- Germany
  - Asse, Gorleben (salt)
  - Konrad (limestone)
- Japan
  - Horonobe (mudstone)
  - Tono (sandstone)



- NAGRA 2002 Project Opalinus generic safety assessment
- Compare “what if?” cases
- Combined ILW, HLW, SF