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NIRAS ONDRAF

5 SEPTEMBER 2025

Safety assessment of the Dessel surface repository

Focus on near field modelling

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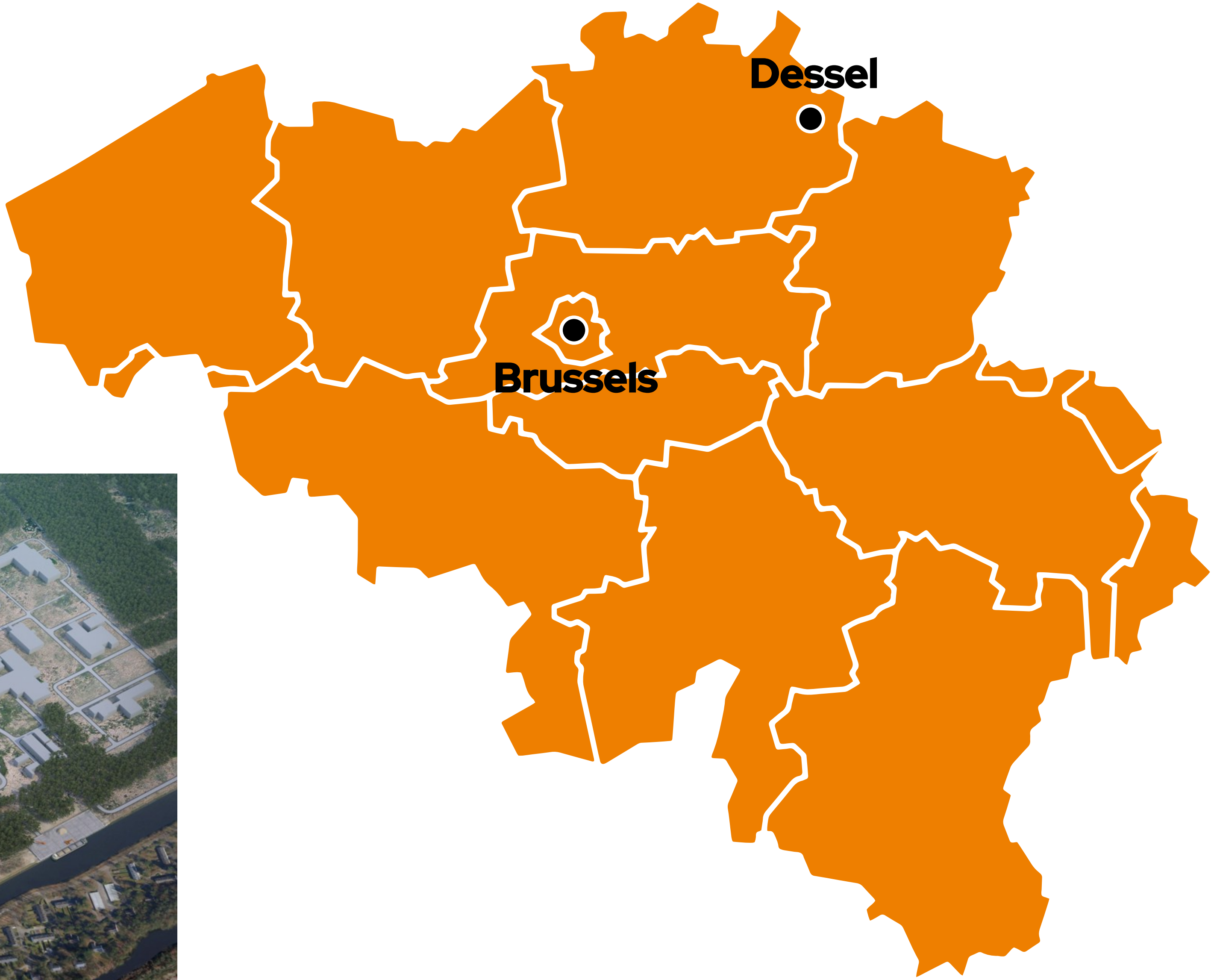
Frank Lemy

Location



The site at a glance

(Pre-)Licensing & upcoming steps

Government decision

2006

2013

Licence application submitted to FANC

2023

23 April 2023 licence by royal decree

2025

Update safety case

2026

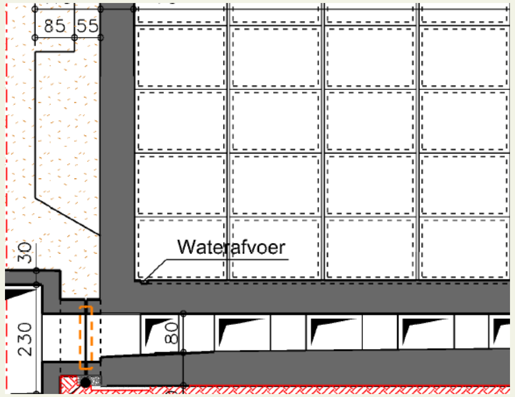
Start of construction

≥ 2029

Start of operations

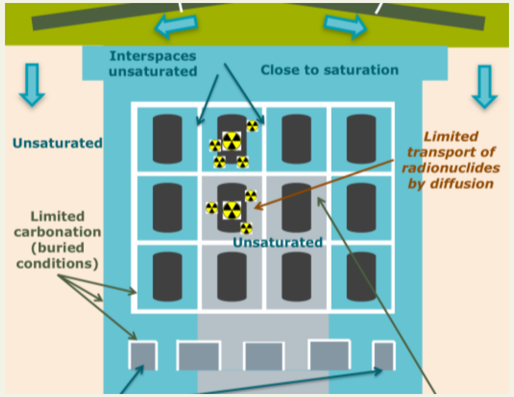
OVERVIEW

NIRAS ONDRAF



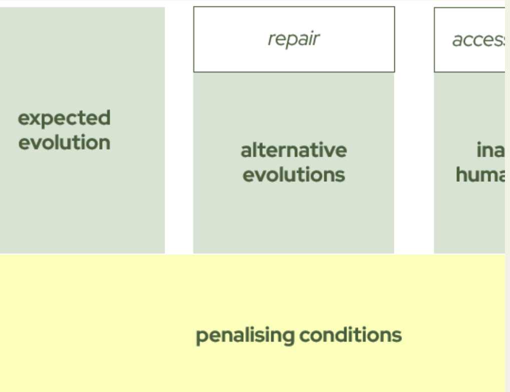
INTRO – THE LOOKS

Repository design: main SSCs



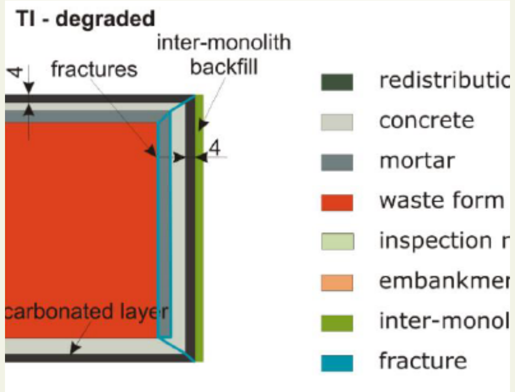
01 - THE PHENOMENOLOGY

Expected evolution



02 - THE STORYTELLING

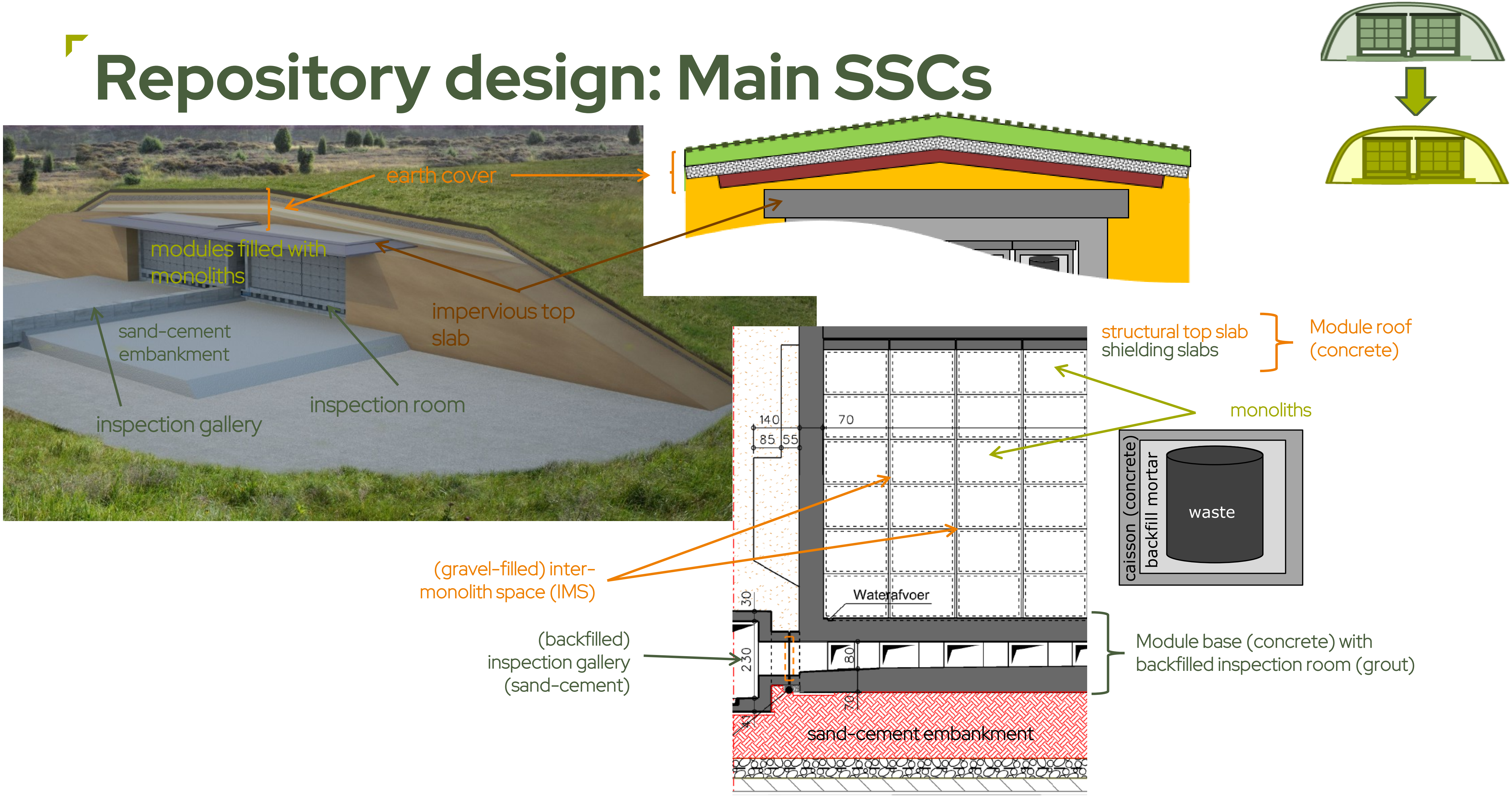
Selection of scenarios



03 - THE MODELS

Near field modelling

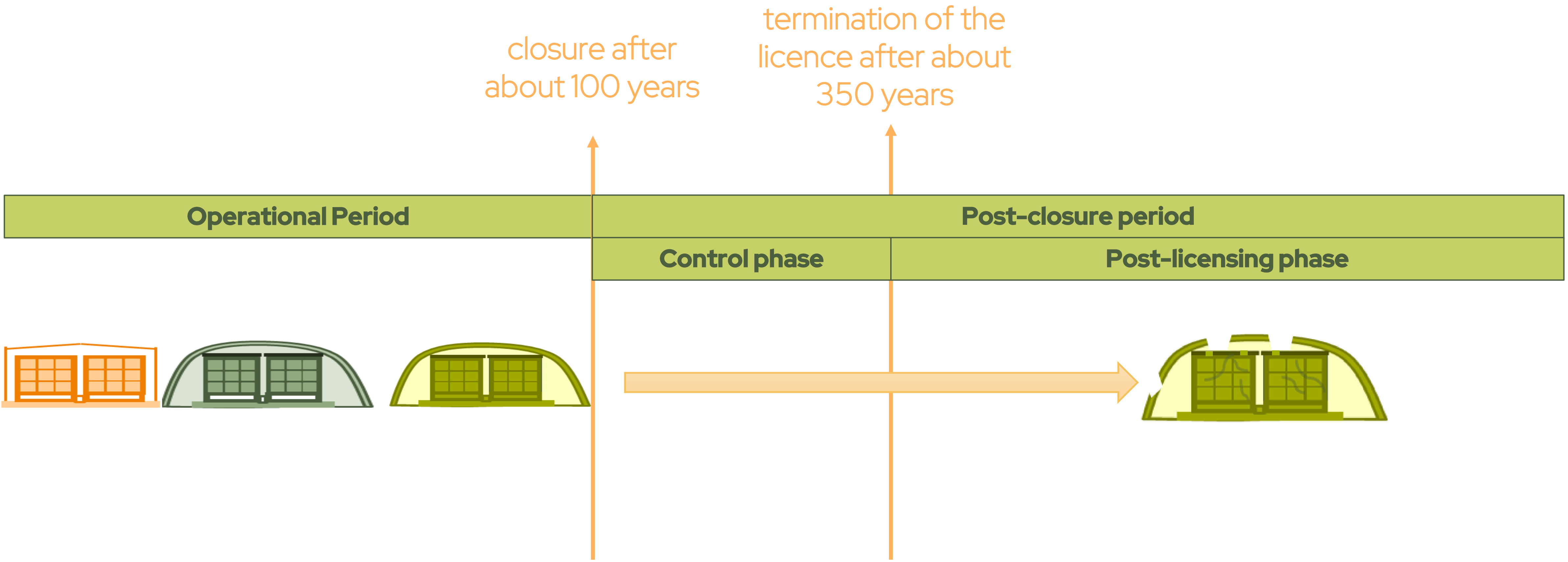
Repository design: Main SSCs



01 Expected evolution

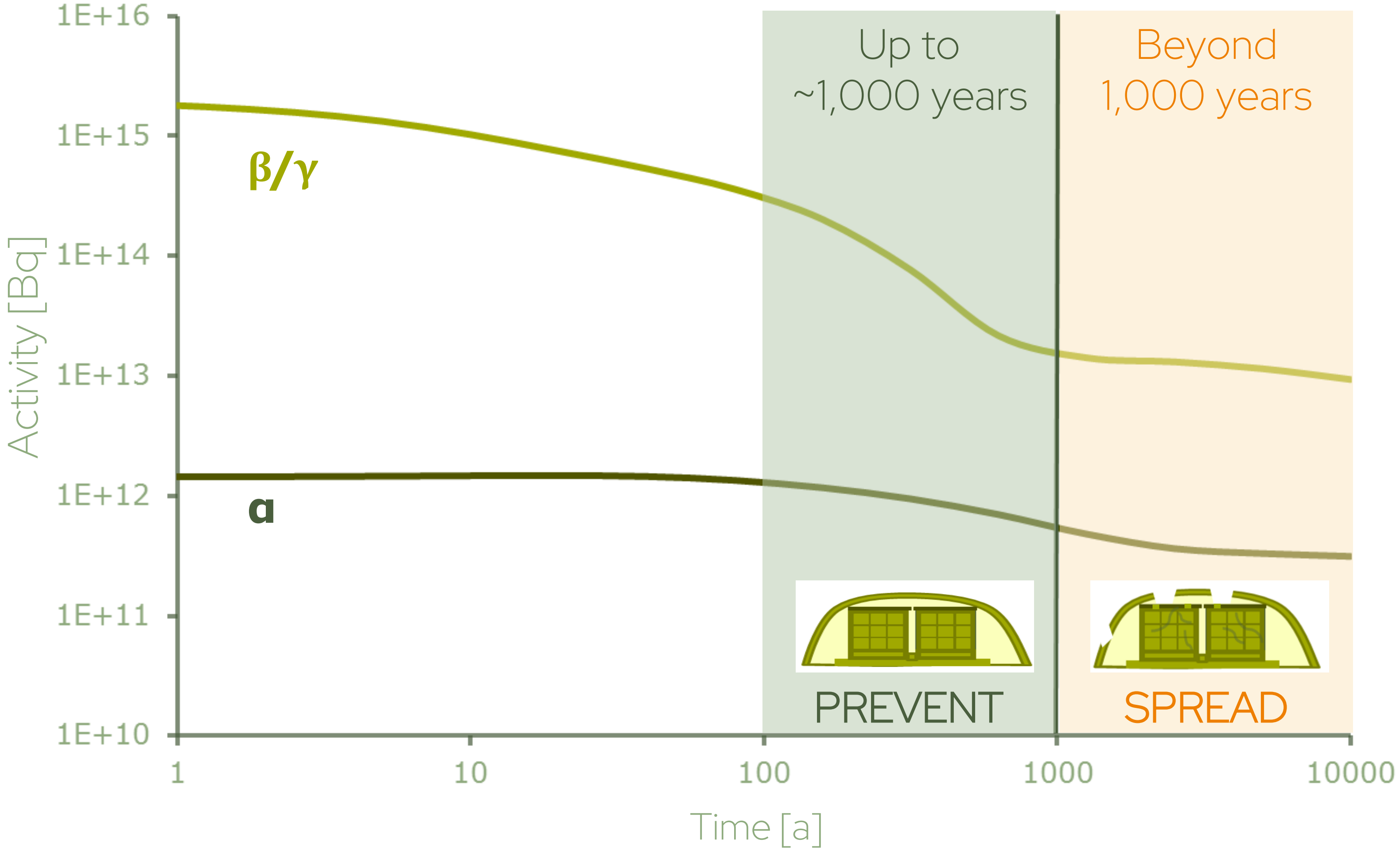
Timeframes
Main degradation processes of cementitious barriers
Water flow
Radionuclide transport

Timescales

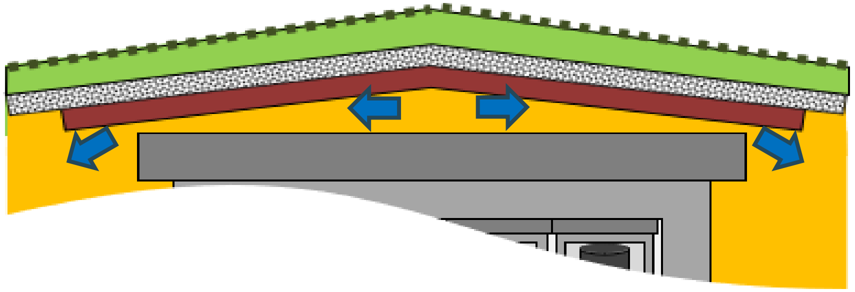

closure after about 100 years
termination of the licence after about 350 years
Operational Period
Post-closure period
Control phase
Post-licensing phase

Containment strategy

Graded approach commensurate to residual hazard



Timeframes up to ~ 1,000 years



Earth cover resists

- possible earthquakes with return periods of ~ 1,000 years
- erosion, thanks to erosion-resistant design of bio-intrusion barrier

→ BURIED CONDITIONS imposed to underlying concrete components

Carbonation as the main degradation mechanism

- virtually halted (very low rates) under buried conditions

Impervious top slab has a key role in limiting water infiltration towards the modules

- Lateral flow of water in (conductive) sand on top/at its sides
- Any percolating water is used to resaturate underlying concrete components (suction)

Timeframes up to ~ 1,000 years

Radionuclide transport is very slow

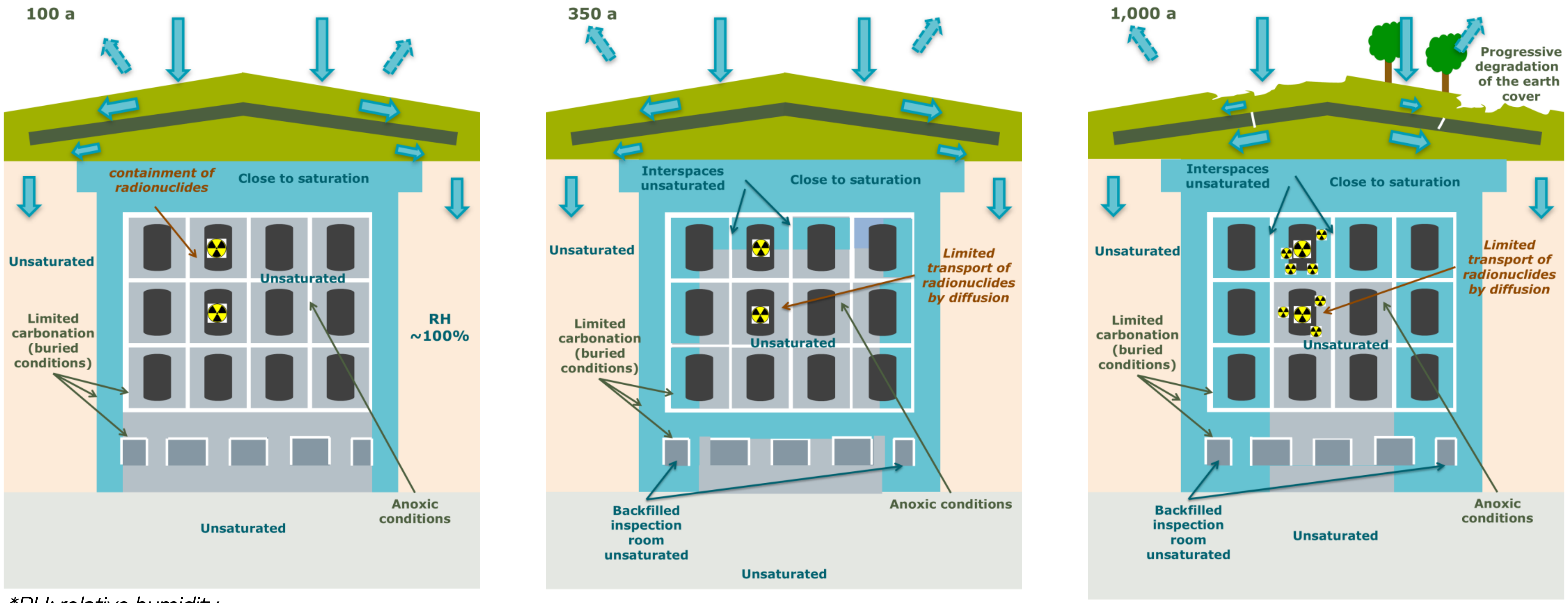
- controlled by diffusion
- mainly within the waste / monoliths

Waste packages should maintain their integrity

- Water needed to initiate/sustain any chemical reactions within the waste, but limited availability
- Passive corrosion of steel packaging → barrier for radionuclide transport
- *ASSUMPTION: Waste conformity criteria are respected → no adverse effects of on surrounding SSCs*

SSCs reach/maintain their target performance over timeframes of ~ 1000 years

Timeframes up to ~ 1,000 years



RH: relative humidity

Deviations from target performance

Local erosion of earth cover

- Gradual process (~ several hundreds of years)
- Local exposure of concrete SSCs to atmospheric conditions
  - Enhanced carbonation
  - Freeze-thaw

Construction imperfections

- No effect while buried conditions prevail
- Might enhance degradation once initiated

Degradation (of cementitious SSCs) may locally be initiated earlier than ~ 1,000 years

Timeframes > 1,000 years

Heterogeneity in evolution of different parts of the disposal system

- many possible (interacting) events and processes
- NO abrupt loss of mechanical properties → degradation of concrete SSCs over a few hundred years

Earth cover degradation → buried conditions no longer guaranteed

- Enhanced carbonation rates
- Exposure to freeze-thaw cycles

Gradual development of fractures in impervious top slab, modules and monoliths

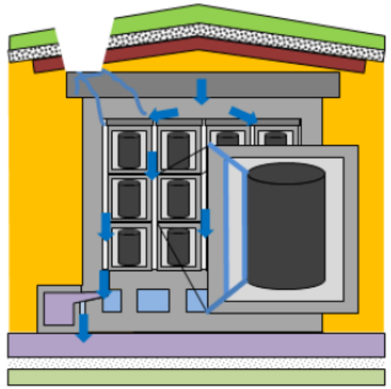
- Preferential pathways for water flow and radionuclide transport

Water infiltration into modules following degradation of the impervious top slab

- still reduced w.r.t. precipitation by *evapotranspiration* on earth cover remnants

Timeframes > 1,000 years

Preferential water flow paths



- shielding slabs and gravel in inter-monolith spaces (IMS) ensure deviation of infiltrating water (away from the waste
- anti-baththub system (ABS) prevents water accumulation inside modules

Radionuclide transport is bimodal

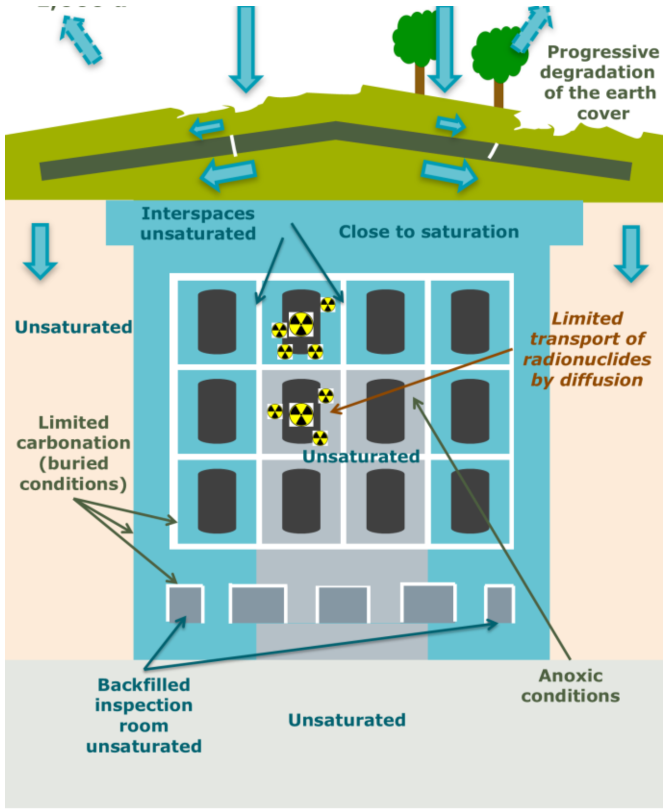
- diffusive transport in low-permeable (concrete/mortar) matrix between fractures
- advective transport in fractures and conductive materials (gravel in IMS, grout in inspection room, sand-cement embankment)

Chemical retention of radionuclides (sorption)

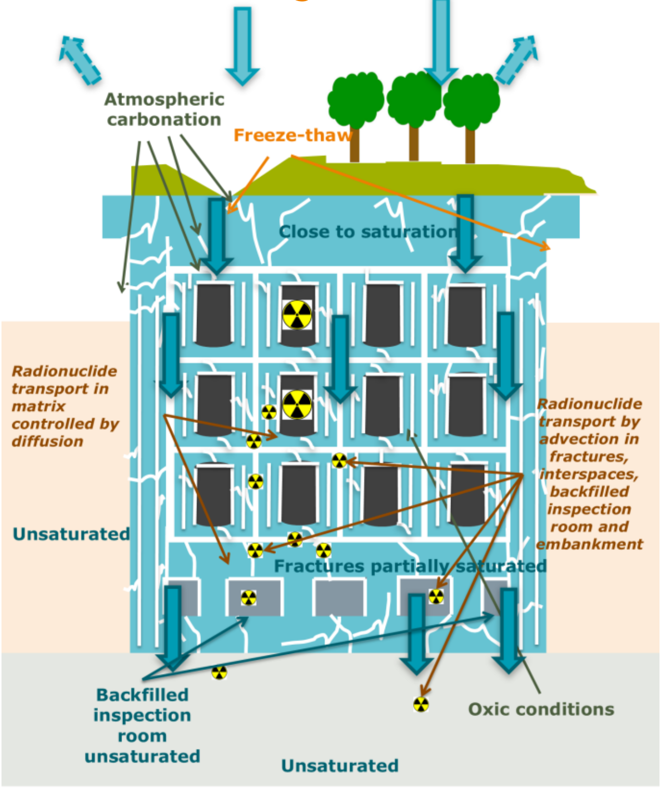
- in cementitious matrix (concrete, mortar, grout in inspection room, sand-cement)
- lower sorption in carbonated parts
- difficult to quantify in fractures

Timeframes beyond > 1,000 years

Structurally 'intact' system at ± 1,000 years



System after several hundred years of degradation



Timeframes > a few thousand years

System evolution surrounded by

- ever-increasing heterogeneity
- ever-increasing uncertainty

Waste/mortar/concrete/cover will eventually turn into rubble

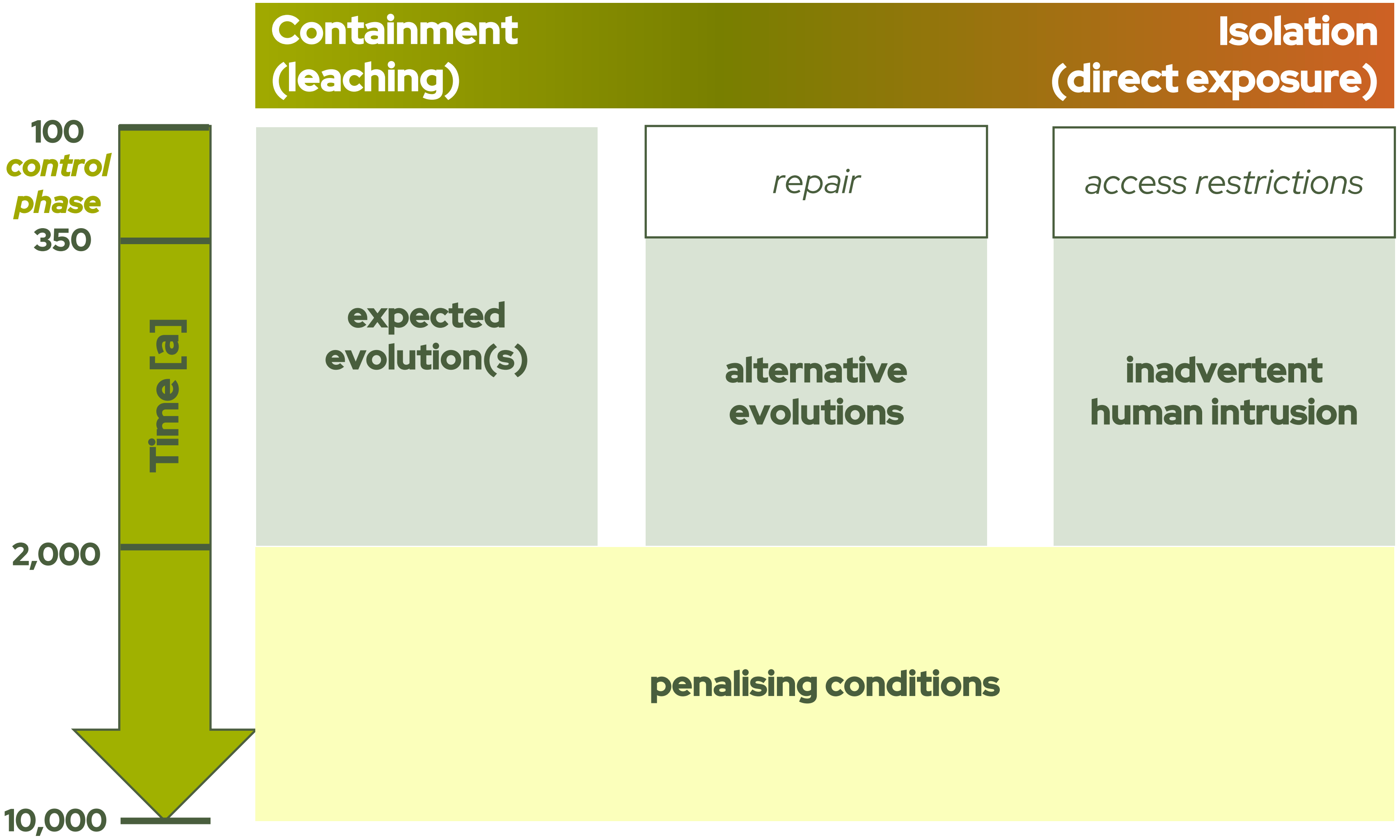
- uncertain configuration
- heterogeneous chemical state (> limited sorption)

Expected evolution – or any (single) path of evolution – can no longer be reliably described

02 Selection of scenarios

Scenarios & timescales
Main premises
Use of features, events and processes (FEPs)

Overview


Containment
(leaching)
Isolation
(direct exposure)
100
control
phase
350
2,000
10,000
Time [a]
expected
evolution(s)
repair
alternative
evolutions
access restrictions
inadvertent
human intrusion
penalising conditions

Expected evolution scenario(s)

Timeframes from closure (~ 100 years) until a few thousand years (2,000 years by convention)

Representative of phenomenologically expected evolution, to the extent possible

Constant climate conditions

- Subtropical climate conditions with rainfall seasonality (dry summers, wet winters)

No reactions in waste that adversely affect SSC performance

Gradual degradation

- 3 out of 4 modules display target performance – degradation from 1,000 years onwards
- 1 out of 4 modules subject to local deviations from target performance – degradation from 650 years onwards

Alternative evolution scenarios

Timeframes from <u>end of controls (350 years)</u> until a few thousand years (2,000 years by convention)

Disruptions of the expected evolution caused by the occurrence of (an) initiating FEP(s)

(Sufficiently) representative of the potential disruption of the expected evolution that they address

Bounding the potential disrusptions in terms of assumed time of occurrence and assumed damage

Alternative evolution scenarios

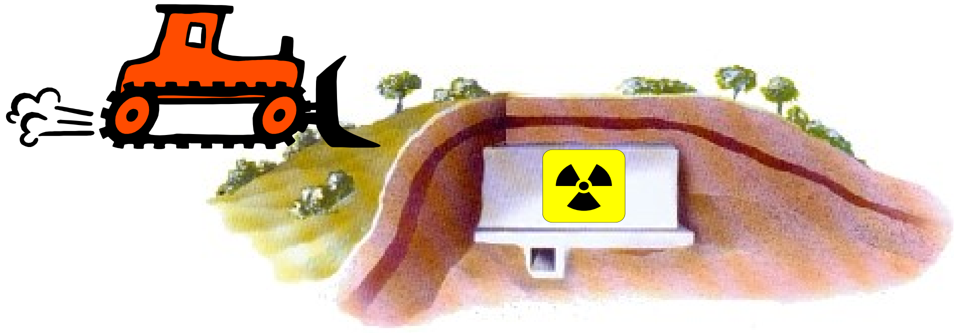
≠ types of threats (~ initiating FEPs) & resulting disruptions

- threats compromising protective role of earth cover → buried conditions no longer guaranteed → early (gradual) degradation
  - e.g. erosion
- threats compromising cover & concrete SSCs directly → fracturing → abrupt (& early) degradation
  - e.g. heavy earthquake
- internal distortions > undetected presence of undesired components in waste (e.g. complexants) → loss of chemical retention capacity
  - e.g. waste with high cellulosic content (> ISA)
- plausible combinations of internal distortions & early degradation

Inadvertent human intrusion scenarios

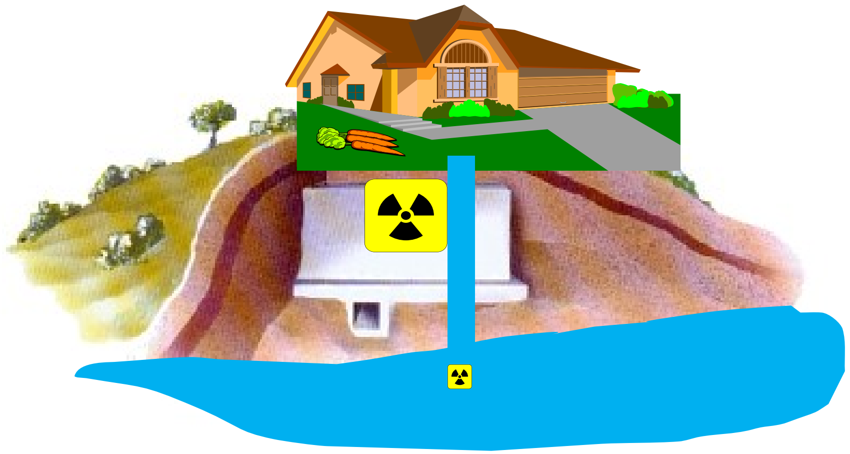
Timeframes from end of controls (350 years) until a few thousand years (2,000 years by convention)

Hypothetical & stylised scenarios



Different effects & exposure groups

- direct → intruder
- deferred – either in terms of isolation or containment → neighbouring population



≠ types of threats & resulting disruptions

- excavation (→ damage) → abrupt degradation
- (well) drilling → "shortcut" for release towards the groundwater
- (core) drilling → lab analysis

Penalising conditions/scenarios

Timeframes from a few thousand years until the end of the assessment timeframe (10,000 years)

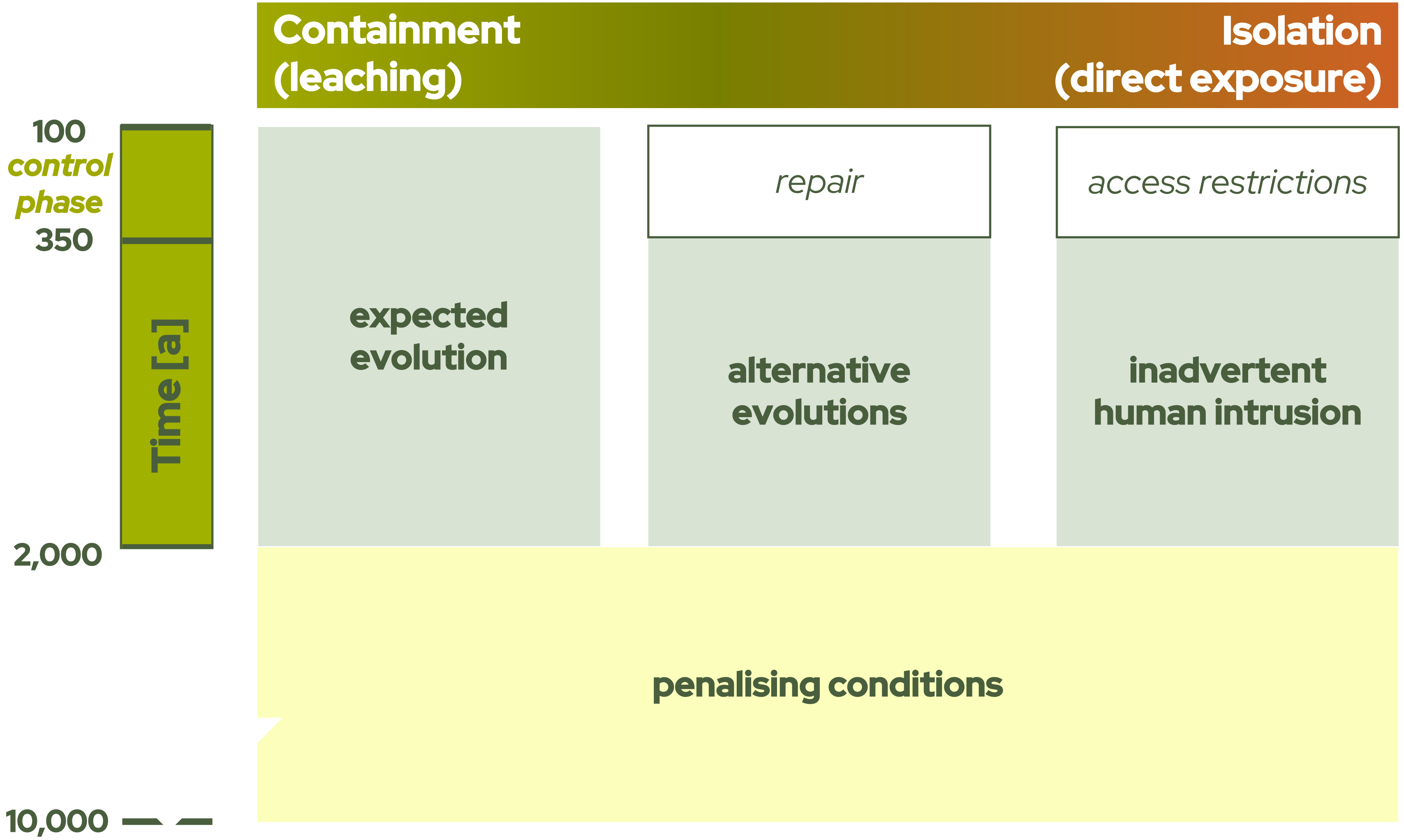
Not linked to (single) evolutionary pathway(s)

Minimal (non-zero) performance

Bounding the radiological impact under a broad range of possible evolutions in the distant future

Overview


near field
modelling scope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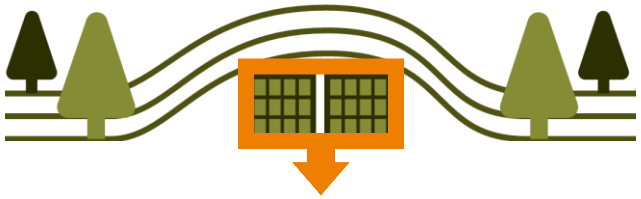
03 Near field modelling

Scope & link with scenarios
Key processes included
Model geometry & implementation
Governing processes

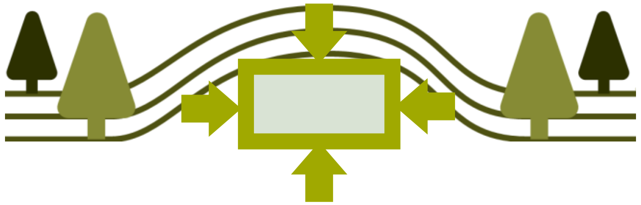
Scope of quantitative assessment

Radiological impact



- flux out of repository (into the groundwater) as a basis for assessing impact to humans (& non-human biota)
- conservative approach
- parameter choices bounding the (maximum) impact over timeframes up to 2,000 years

System performance



- performance indicators describing the migration of radionuclides as a function of time
- aim for representative approach
- best-estimate parameter values where possible

adopted near field models (will) differ only in terms of parameterisation

Scenarios > models

Starting point = models representing expected evolution

Disruptions (alternative evolution or human intrusion) imply

- early loss of buried conditions
- early development of fractures in concrete SSCs
- altered sorption behaviour
- in extreme cases
  - more extensive fractures & less effective water deviation from monoliths/waste
  - (local) shortcut for transport out of the modules towards the aquifer

For the associated models, this implies (as compared to models associated with expected evolution)

- earlier occurrence of fractures → early degradation onset
- lower sorption capacity of cementitious SSCs → zero sorption
- in extreme cases
  - more fractures & more water in contact with waste
  - bypass of underlying SSCs as radionuclides are released from monoliths → SSCs excluded from model

similar near field models associated with the different scenarios

Processes considered (1/2)

	Before degradation ($t < t_b$)	After degradation ($t_b < t <$ 2,000 years)
Earth cover	**imposing buried conditions**	**(partial) exposure of underlying SSCs to atmospheric conditions**
Relevant degradation processes	**carbonation** negligible effect	**carbonation** front development abstracted into carbonated layer with fixed thickness
	fracturing no through-going cracks	**fracturing** stylised networks of (connected) fractures in modules and monoliths
Water regime	**saturation state** partial saturation	**saturation state** • modules and monoliths close to saturation • embankment partially saturated
	water flow no flow (suction > re-saturation)	**water flow** • water infiltration (drainage from earth cover) • water redistribution within module • no flow in low-permeable matrix of module concrete & monoliths • flow in conductive materials

Processes considered (2/2)

	Before degradation ($t < t_b$)	After degradation ($t < t_b < 2{,}000$ years)
Conditioned waste (CW) packages	**containment** within steel packaging	**release from waste** • instantaneous release • sorption on HCP in waste (K_d approach)
Bulk waste	**release from waste** • instantaneous release • sorption on HCP in backfill mortar (K_d approach)	
Radionuclide transport	**physical** diffusion-controlled transport	**physical** • diffusion-controlled transport in low-permeable matrices (incl. waste form) • advection-controlled transport in fractures, IMS, grout (inspection room), sand-cement • dispersion in grout & sand-cement
	chemical sorption on HCP in cementitious SSCs (K_d approach)	**chemical** • sorption on HCP in cementitious SSCs (K_d approach) • no sorption in fractures

Model geometry

2D models

- needed to conceptualise existing heterogeneity within the disposal system (& resulting heterogeneity in water flow & radionuclide transport trajectories)

Symmetry considerations

- single stack of monoliths → module walls excluded
- simplified to half a monolith (+ half of adjacent IMS) in horizontal direction

Boundary conditions

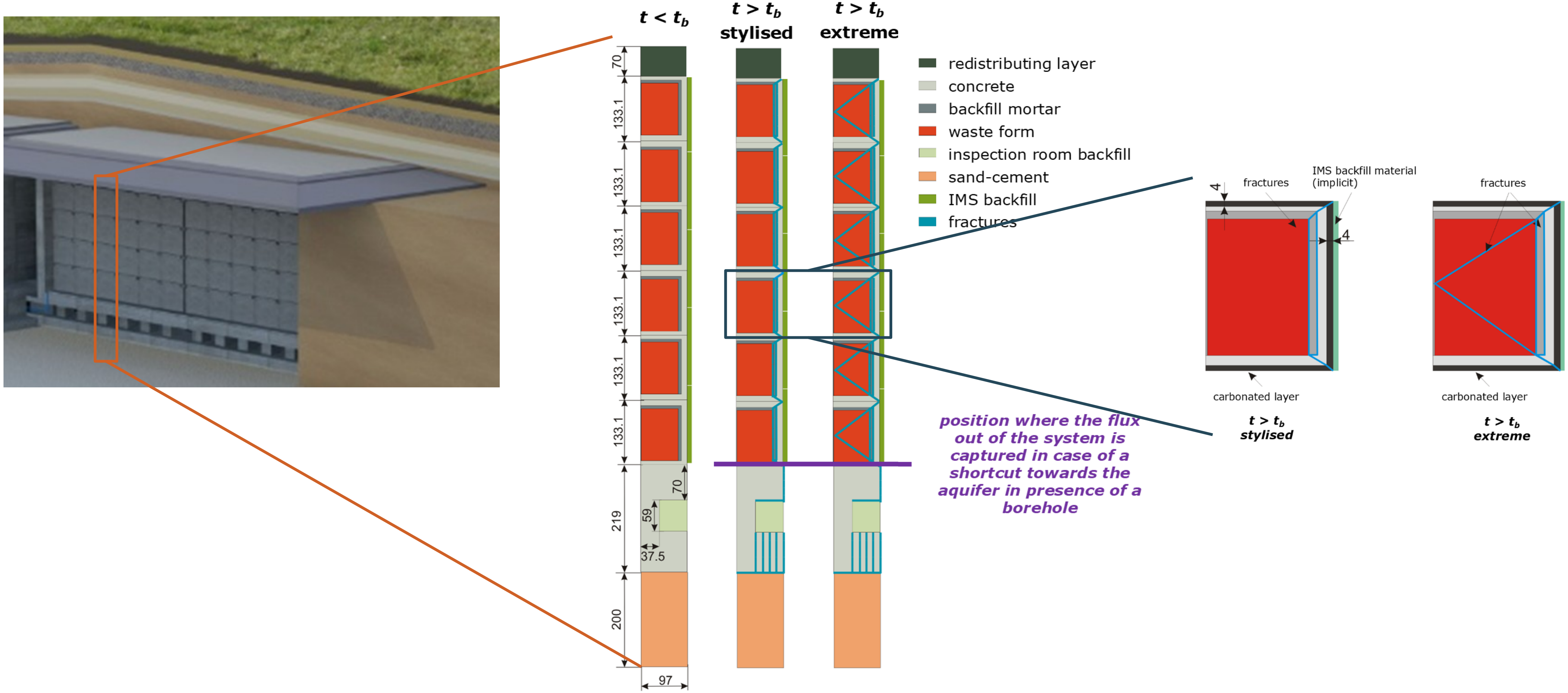
- water flow through cover imposed as a boundary condition → earth cover/impervious top slab excluded

Model geometry

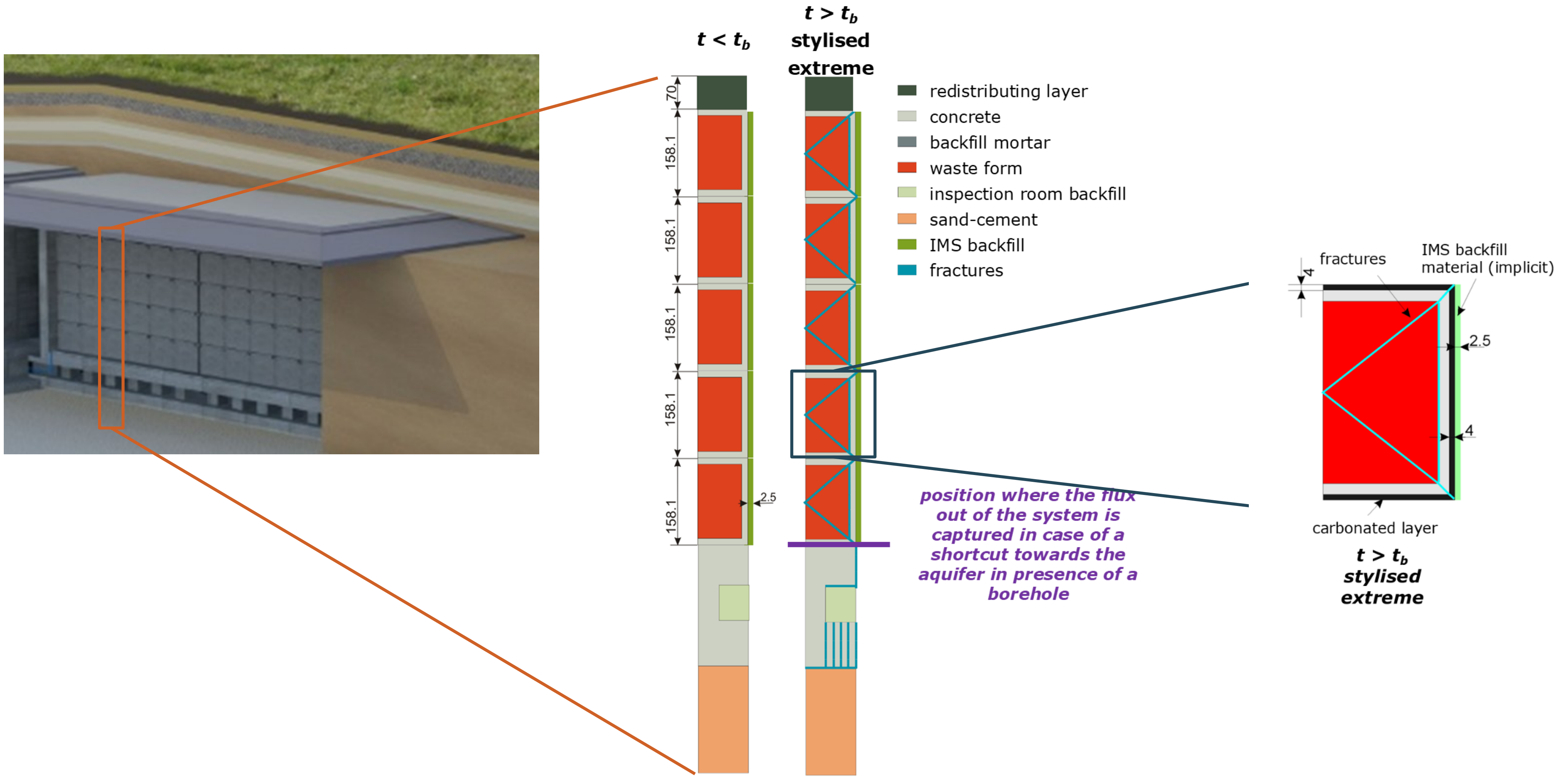
Model variants

- monolith types
  - monoliths with conditioned waste (CW) packages –> homogenised waste form within drum
  - monoliths with bulk waste –> homogenised waste form (waste + backfill mortar) within caisson
- time dependence
  - before degradation
  - after degradation $(t > t_b)$
- parameterisation
  - radiological impact calculation : conservative
  - performance analysis : best estimate

Model geometry (monoliths with CW)



Model geometry (monoliths with bulk waste)



Model implementation: key features

Water redistribution

- pheno: by means of gravel-filled inter-monolith space, facilitated by fibre-reinforced shielding slabs
- model: redistributing layer, redistribution steered by difference in width

Gradual degradation

- gradual (linear) increase of water infiltration towards max. value of 480 mm/a over 350 years
- 5 steps from t_b onwards, 75-year interval, implemented by post-processing of outward fluxes

Implicit representation of fractures (and IMS)

- 1D boundary elements with underlying with of 1 mm (25 mm) → tangential derivatives defining flow

Governing processes

Redistribution of infiltrating water

- limited amount of water in contact with waste

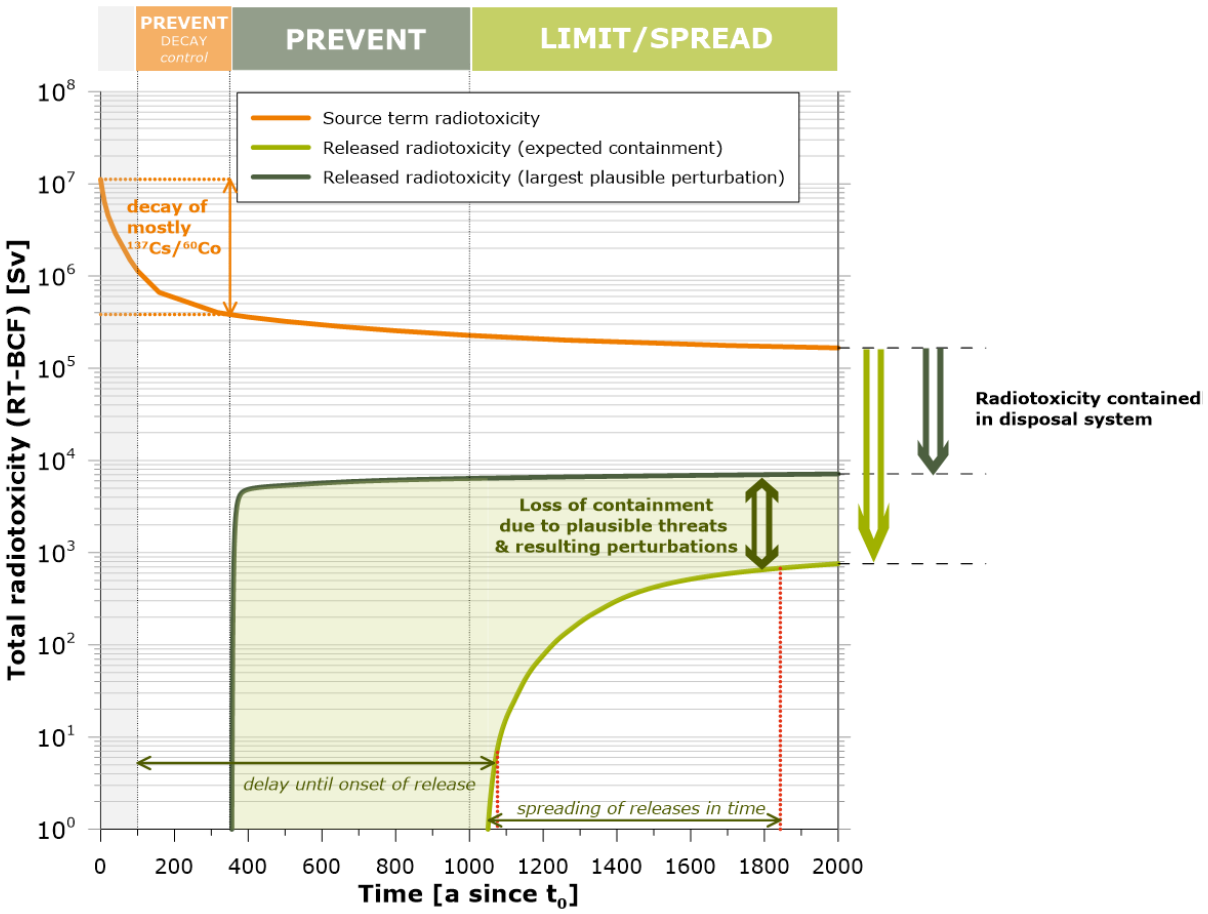
Diffusive migration of radionuclides from waste form towards fractures

- advection (with water flow) is the dominant downward migration process for radionuclides ending up in fractures
- bypass of sorption capacity of low-permeable concrete/mortar matrix

Grout in inspection room & sand-cement embankment as conductive sorbing media

- downward migration steered by advection-dispersion
- delay of releases of sorbed radionuclides from the system → timeshift of peak fluxes

Containment vs. hazard



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Thank you for your attention

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