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Integrated safety case development for deep geological repositories

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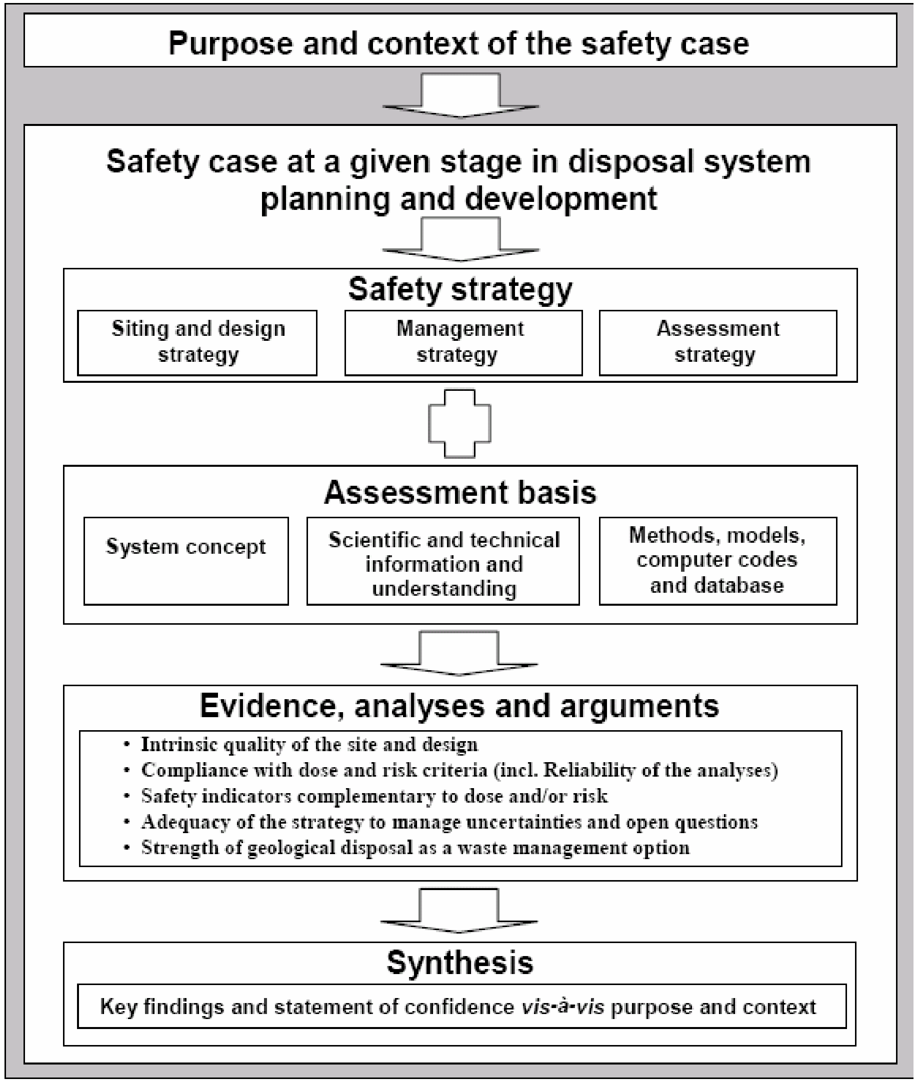
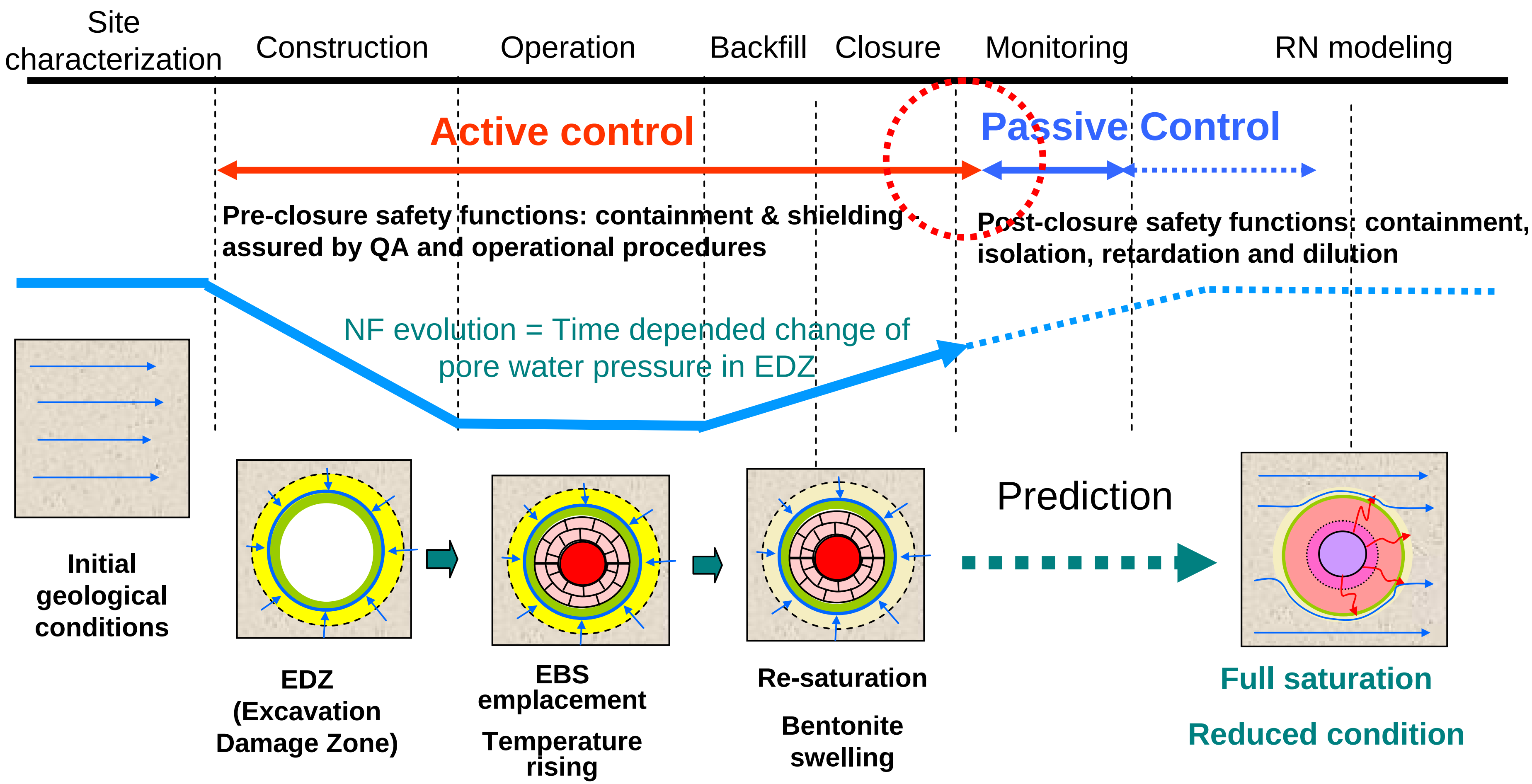
Introduction - the Safety Case in context

- Demonstration of safety requires more than conventional performance assessment, hence widespread use of "Safety Case"
- Emphasis to date is on post-closure safety; as repositories move closer towards implementation, more aspects need to be considered
- In real life, trade-offs are needed between factors influencing operational safety / practicality and post-closure safety
- There may be benefits in widening the definition of "Safety Case" to explicitly account for all the issues to be considered when decisions associated with repository design are made



OECD/NEA 2004

Stepwise development of the Safety Case



Safety case based on modelled NF evolution supported by demonstration experiments

...used for licensing

Safety case confirmation based on improved NF understanding gained during construction and operation

...used for safety reviews

Final safety case containing best understanding of post-closure NF evolution

...used for justify repository closure / transfer of liabilities

Components and application of the Safety Case

Provisional site-specific safety cases

Intermediate SC reviews

H12 SC **generic** → SC for PI selection → SC for DI selection → SC for site selection → SC for licensing → → → SC for closure

Changes:
technical
regulatory
socio-economic

Changes:
technical
regulatory
socio-economic

Total synthesis:
technical
regulatory
socio-economic

Total synthesis:
technical
regulatory
socio-economic

Synthesis of
Site understanding
Site-specific design
State-of-the-art system understanding

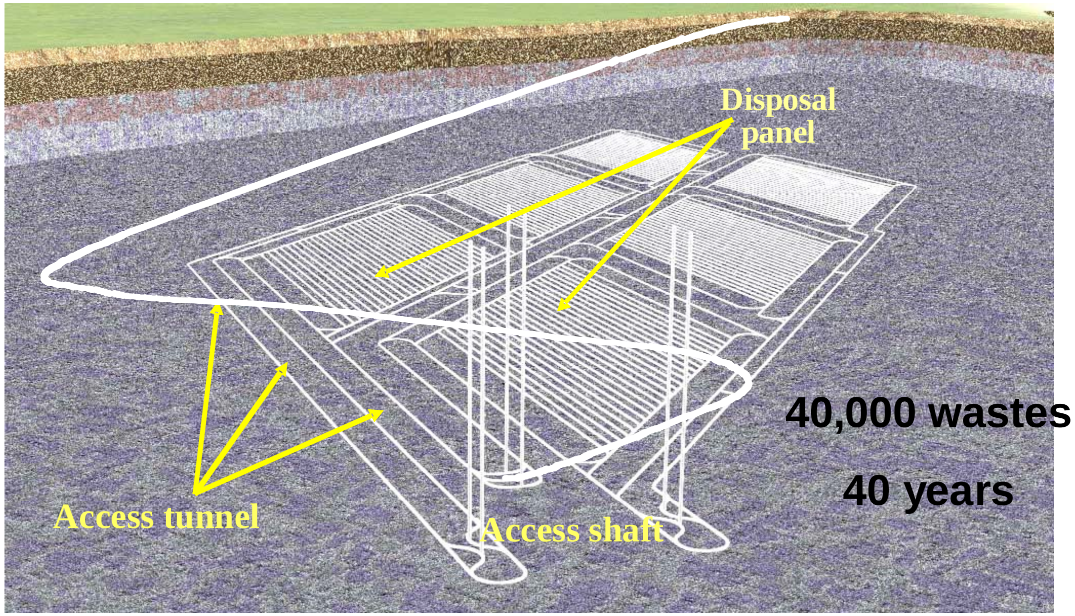
Regulatory constraints:
goals
boundary conditions (e.g. cut-off times, treatment of special scenarios)

Socio-economic BCs:
acceptance
financial constraints
...

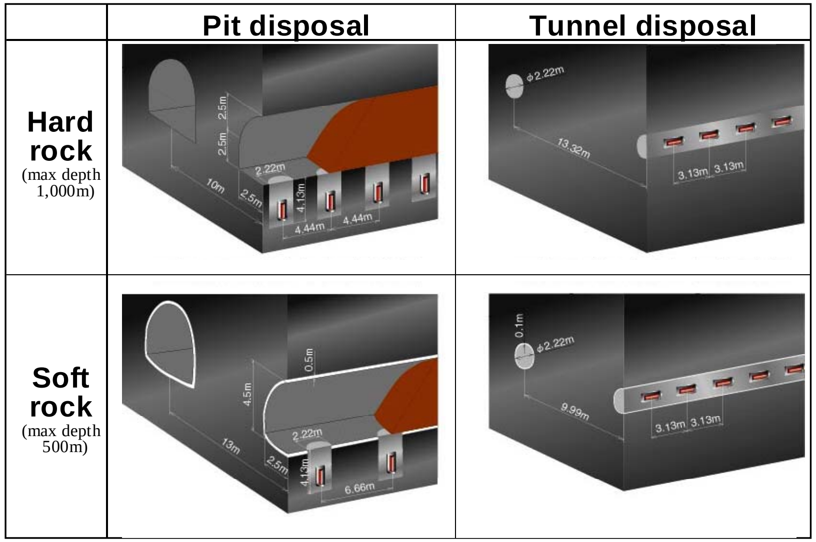
The provisional safety cases need to:
- **confirm basic site / concept safety**
- **provide input for site-specific comparison of design options**
- **provide support for site comparison**
- **form a transparent record to support licensing**

Example of application

- Japanese disposal concept for vitrified HLW from reprocessing
- Generic design based on robust EBS
- Post-closure safety requires assured quality of the emplaced engineered barriers
- Operational safety requires very high reliability of tele-operated equipment: procedures should be simple, fail-safe and allow easy recovery in case of perturbations



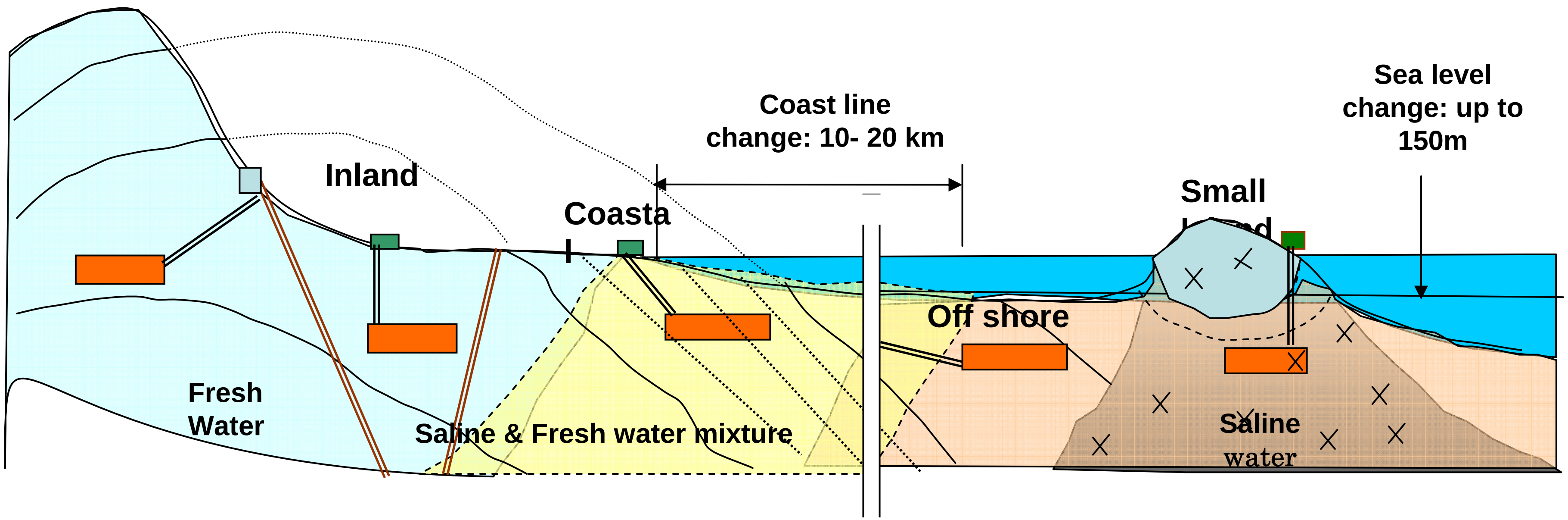
Repository layout



Potential Siting Environments in Japan

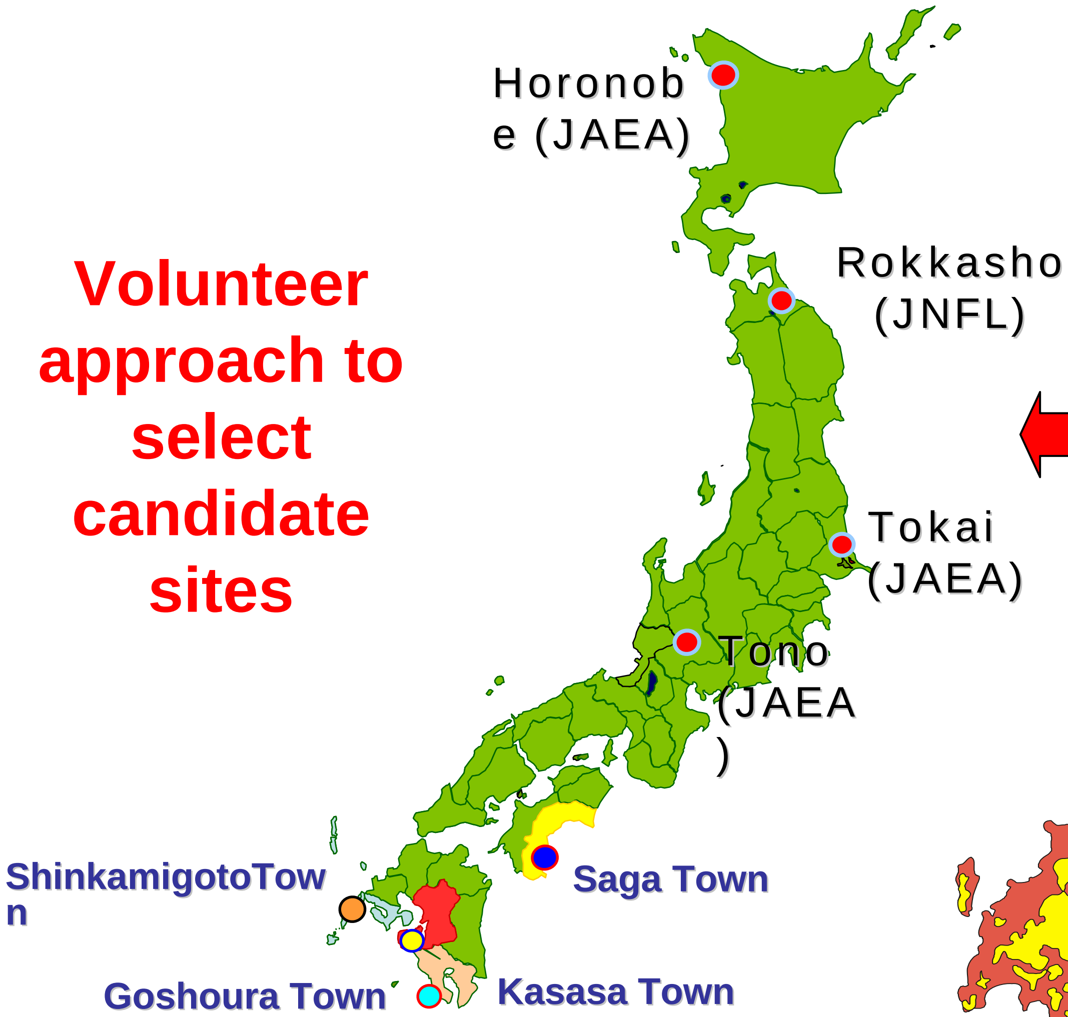
Keeping Flexibility

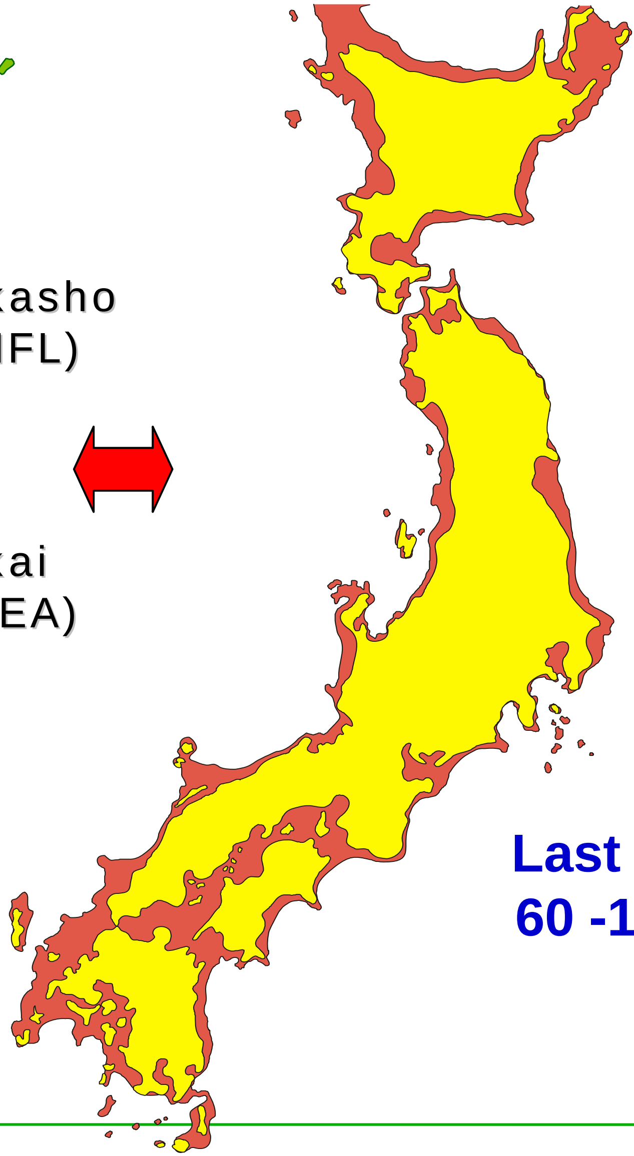
Geological and Geomorphological Environment	Site Characterization	Repository design, Construction and Operation	Performance Assessment



Key issues: Future Environmental Evolution

Volunteer approach to select candidate sites

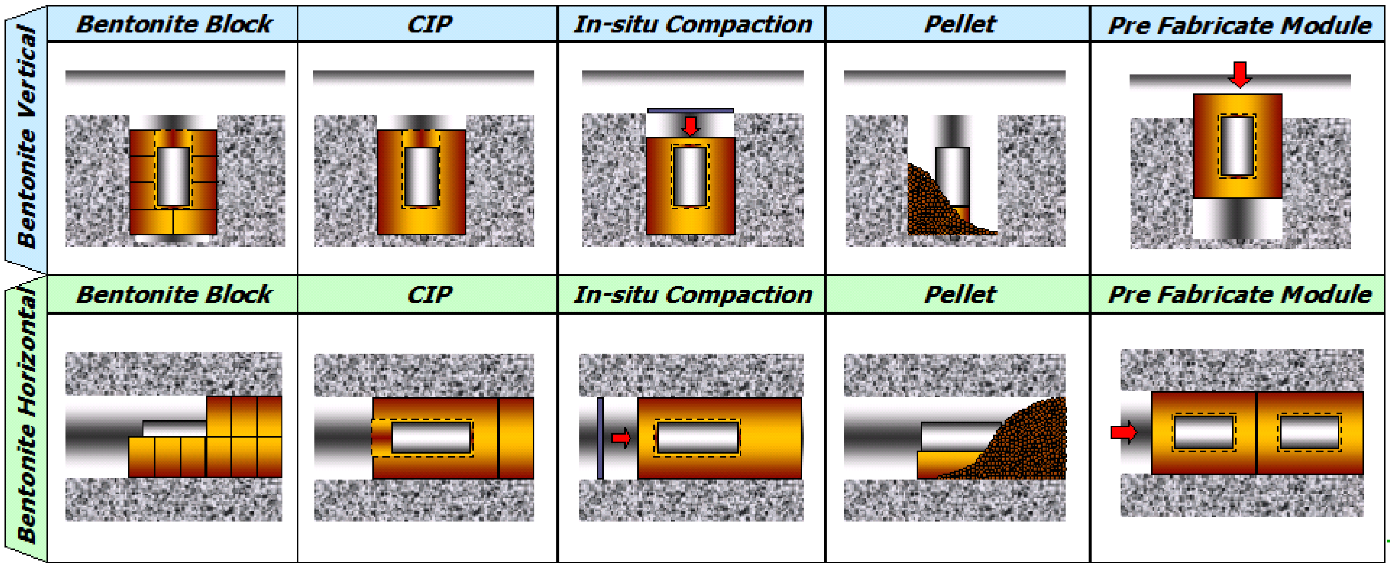




Last ice age: 60 -10ka BP

Remote handled EBS emplacement

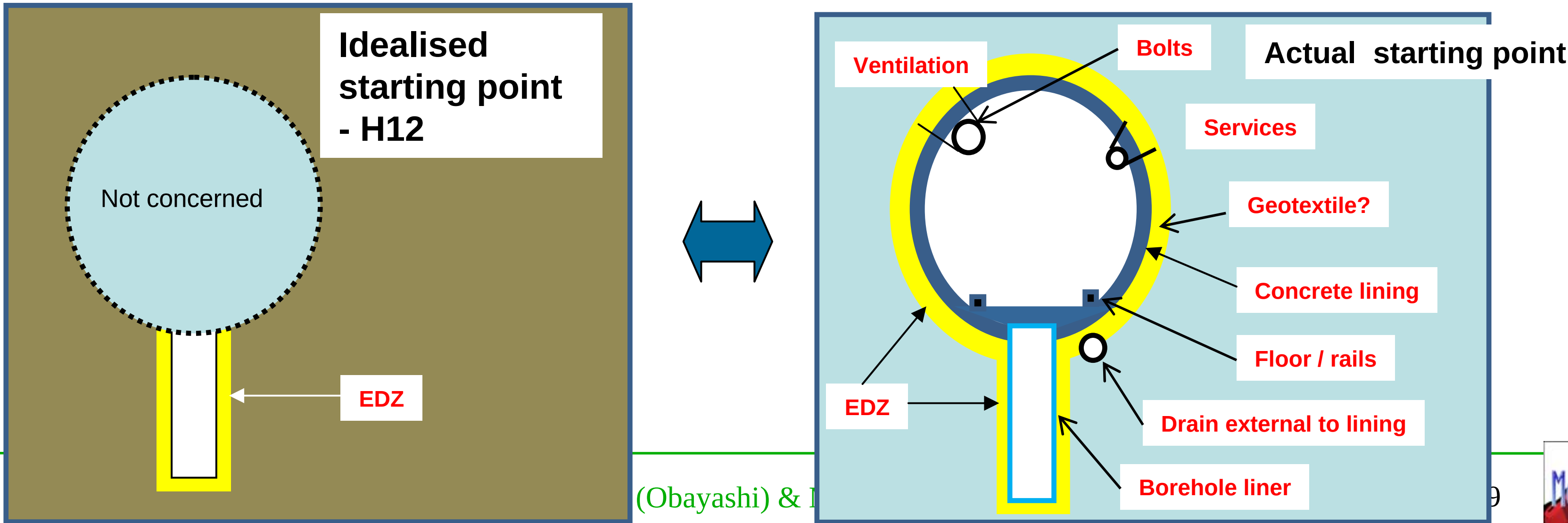
- To form a basis for design optimisation, a wide range of different operational procedures were examined for both vertical and horizontal emplacement options
- Although, in principle, all are feasible and would meet post-closure safety requirements, there are considerable differences in practicality and operational robustness
- For sensible comparison, the simple sketches that formed the basis for laboratory tests need to be transformed into operational procedures appropriate to a working repository



Idealised concepts for overpack / buffer emplacement studied in the RWMC Remote Handling project

Realistic starting point

- For operational analysis, idealised concepts used in the past have to be replaced with realistic specification of the components needed for a safe facility:
  - Drainage systems
  - Tunnel & borehole liners
  - Borehole caps & plugs
  - Temporary infrastructure for ventilation, power supply, communication, monitoring, etc. which may leave traces after its removal
  - Infrastructure that may be abandoned in place – rails for heavy equipment, lifting plates, transport shells, etc.



Expanded Safety Case definition

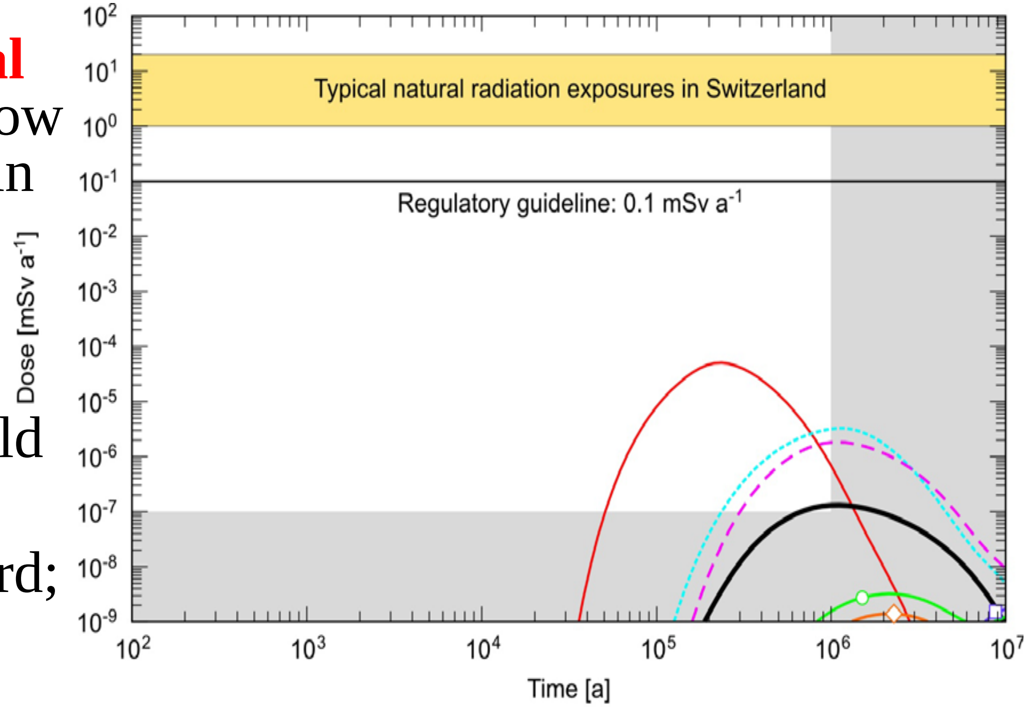
- In order to ensure that all relevant factors are considered in the decision making process for selection of repository design variants, it is useful to consider an expanded definition of the Safety Case that explicitly acknowledges all the issues that need to be considered in a real construction project

NUMO design factors

1	**Long-term safety**	robustness of the post-closure safety case
2	**Operational safety**	conventional and radiological safety of construction, operation and decommissioning
3	**Engineering feasibility**	fundamental feasibility of construction and operation to defined quality levels
4	**Engineering reliability**	practicality of implementation in view of operational boundary conditions and robustness with regard to potential perturbations
5	**Site characterisation**	effort required to satisfy technical requirements for site characterisation and monitoring data
6	**Retrievability**	ease of retrieval after emplacement
7	**Environmental impact**	extent of all environmental impacts associated with repository implementation
8	**Socio-political and economic aspects**	factors contributing to costs and acceptance by all key stakeholders

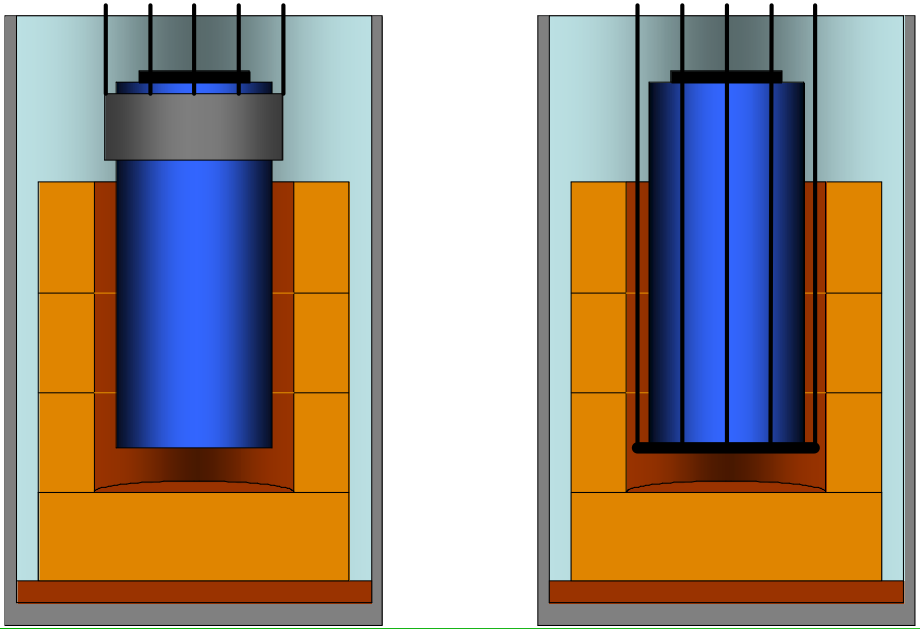
Post-closure safety in perspective

- Assuring safety after repository closure is clearly important for acceptance of a project, but current repositories have huge safety reserves - maximum **hypothetical** risks are orders of magnitude below regulatory limits and occur only in the distant future
- Construction and operation are complex and hazardous jobs (conventional risks); design should reduce **real** risks to workers
- Costs are huge compared to hazard; principle of sustainability would suggest that use of valuable resources in such projects should be kept within reasonable bounds



Trade-offs

- There is rarely a best possible solution to an engineering problem - usually a balance has to be made between pros and cons of different options, e.g. between variants:
  - that minimise the amount of additional materials left in place
  - that are less vulnerable to perturbations (e.g. loss of power)
  - that are easier to reverse / remediate in case of accidents

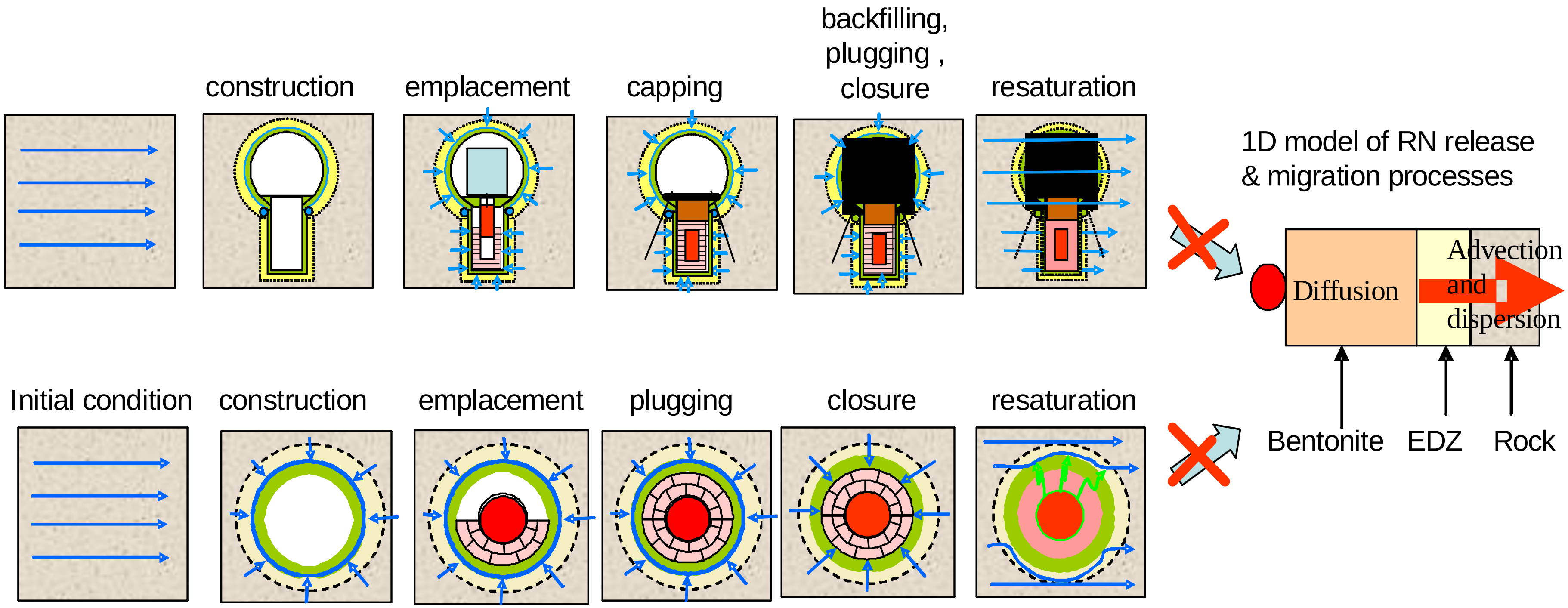


Variants to add operational robustness to an electromagnetic hoist for overpack emplacement:
- left; mechanical lifting collar
- right; lower support platform that is left in place

Realistic safety assessment (1)

Long term safety is clearly important, but must be quantified in a realistic manner

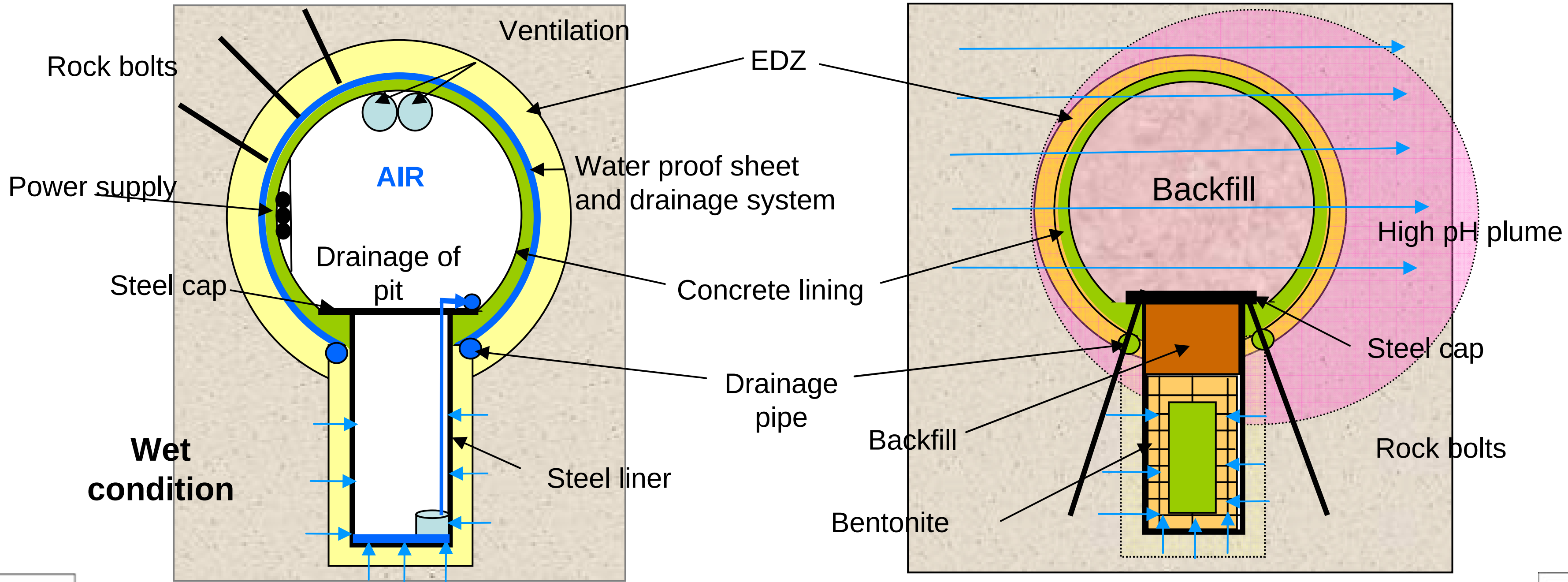
- Models must be able to consider the impact of different geometries and also system evolution during construction and operation in order to distinguish between different operational variants



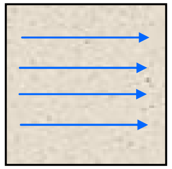
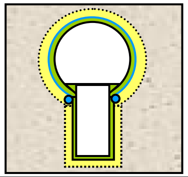
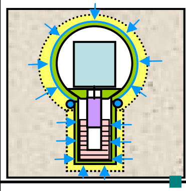
Realistic safety assessment (2)

- Models must also be able to evaluate the long-term consequences of all materials left in place in order to provide input for decisions on trade-offs with operational safety / practicality

Look at just before EBS emplacement and Just after closure



Storyboard: Influence on Bentonite Qualities

Influence Factors on EBS properties	Initial stage 	Before emplacement 	During emplacement 						
EDZ - Stress - Pore water pressure	500m depth 10MPa 5Mpa	Excavation 0 MPa	Stress recovery Pore water pressure recovery		5MPa				
Steel lining - Corrosion, swelling - Gas			Corrosion →expansion →gas						
Bentonite - Resaturation, swelling - Erosion, deformation -Degradation	Drainage of emplacement pit		Setting bentonite blocks	**Resaturation → swelling pressure** **Resaturation →High pH plume →degradation**					
Overpack - Corrosion, failure - Expansion - Gas			Setting overpack						
Vitrified Waste - Radiation, heat - Dissolution			Ventilation temperature up						
Gaps - Block-OP - Block-wall			Resaturation → Swelling →Reduce gap						
Capping system									
EBS backfilling									
Tunnel liner, Drain, backfilling			Dissolve concrete →high pH plume						

Initial Quality of Bentonite

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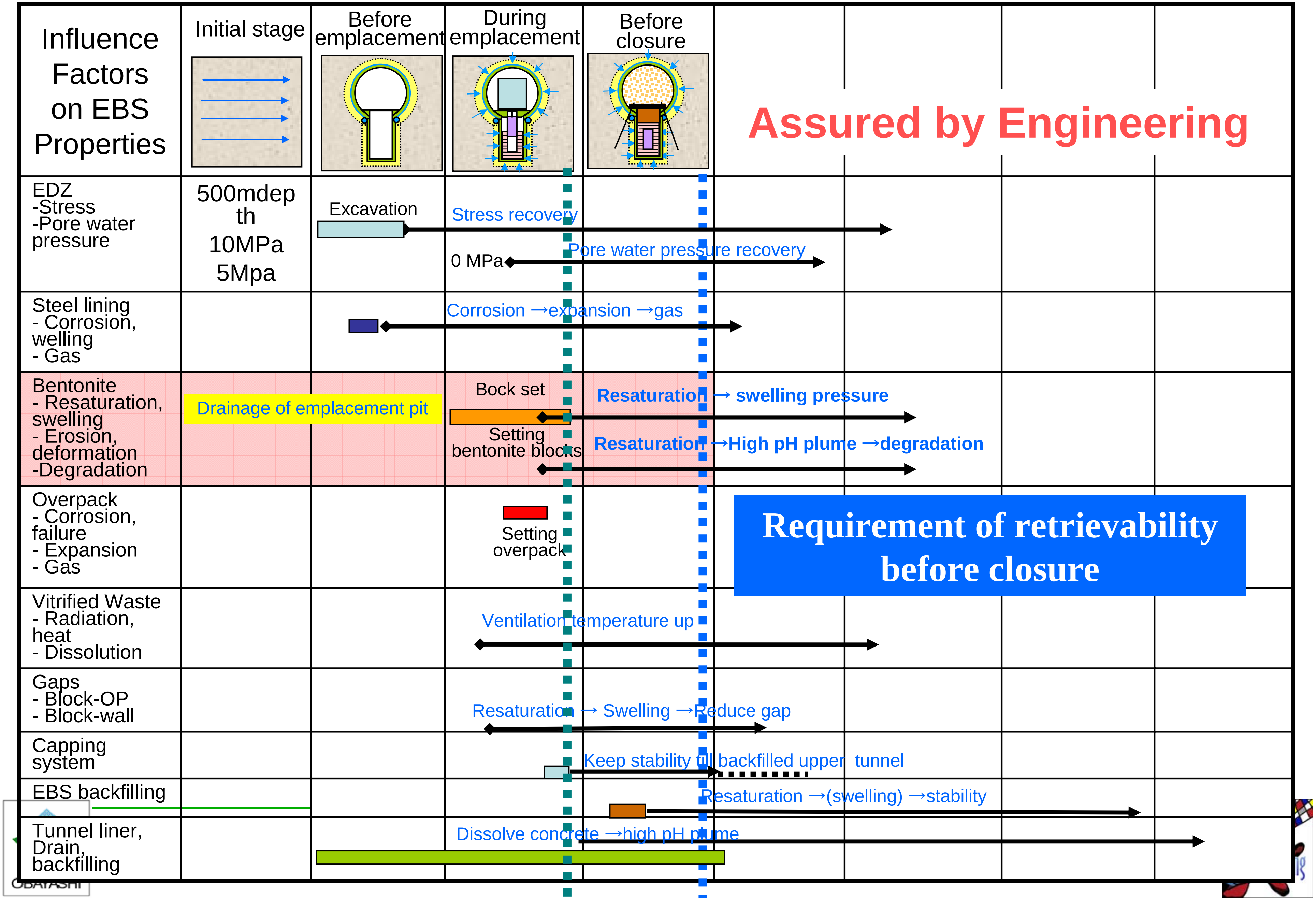
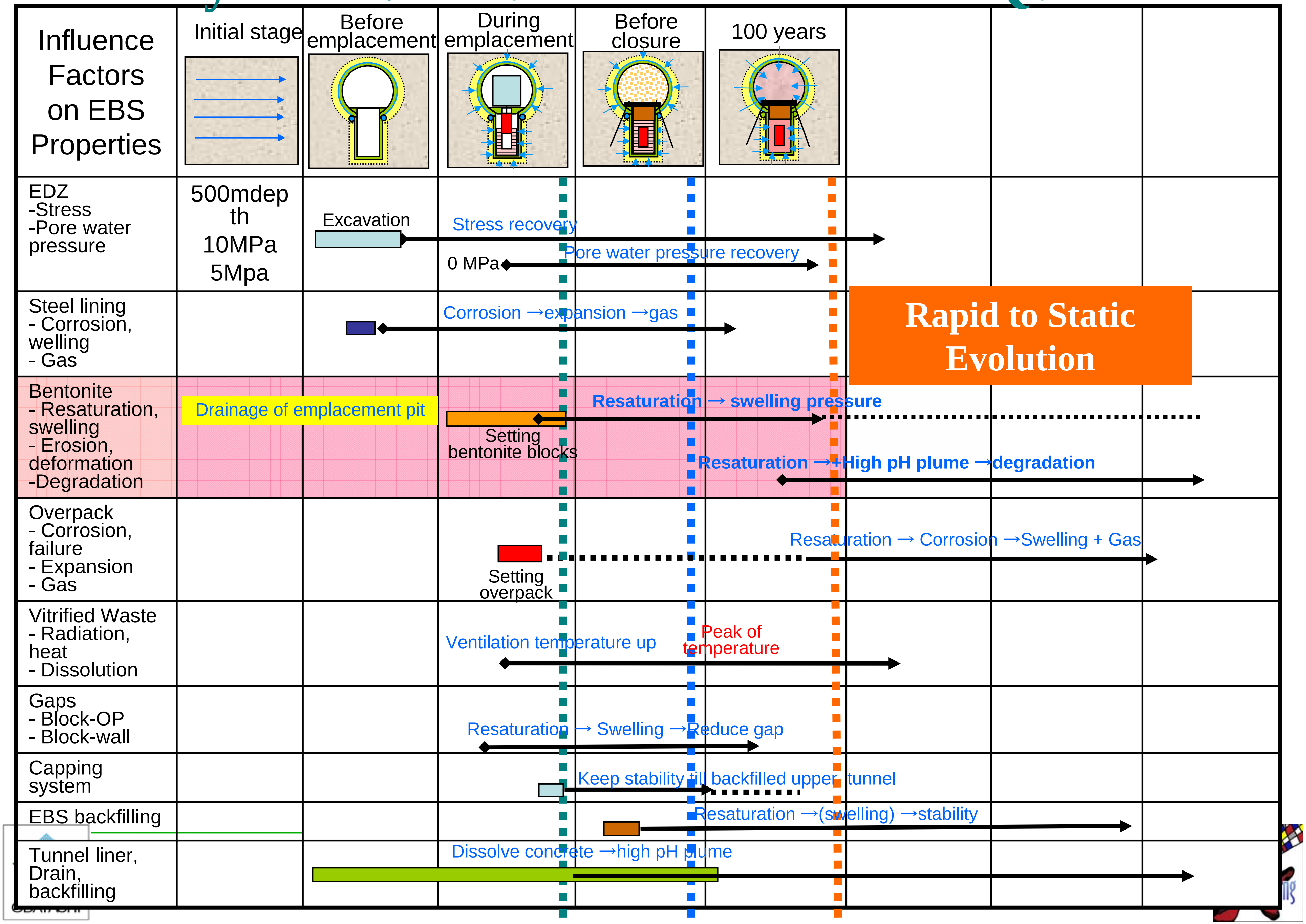
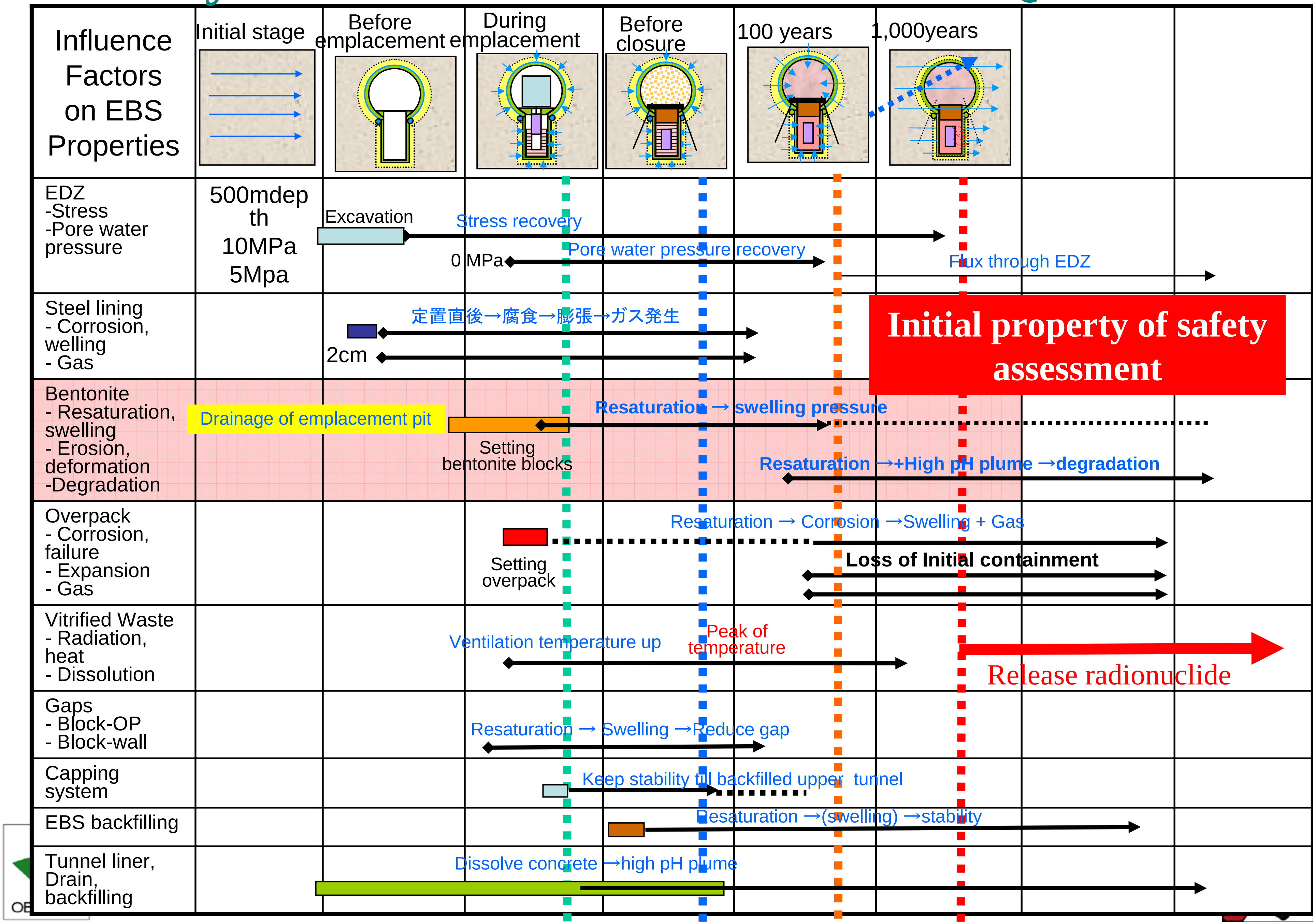
Storyboard: Influence on Bentonite Qualities



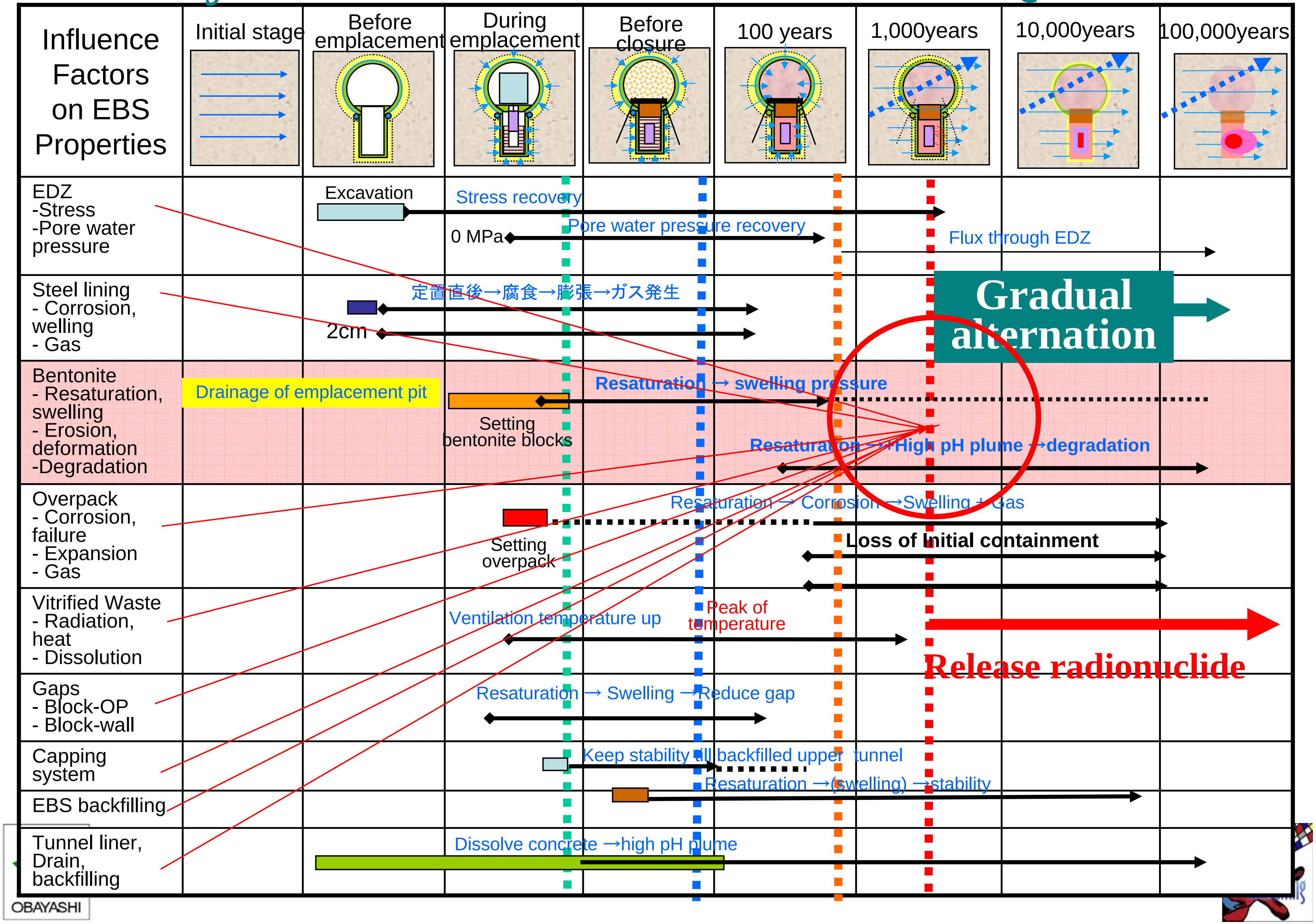
Storyboard: Influence on Bentonite Qualities



Storyboard: Influence on Bentonite Qualities



Storyboard: Influence on Bentonite Qualities



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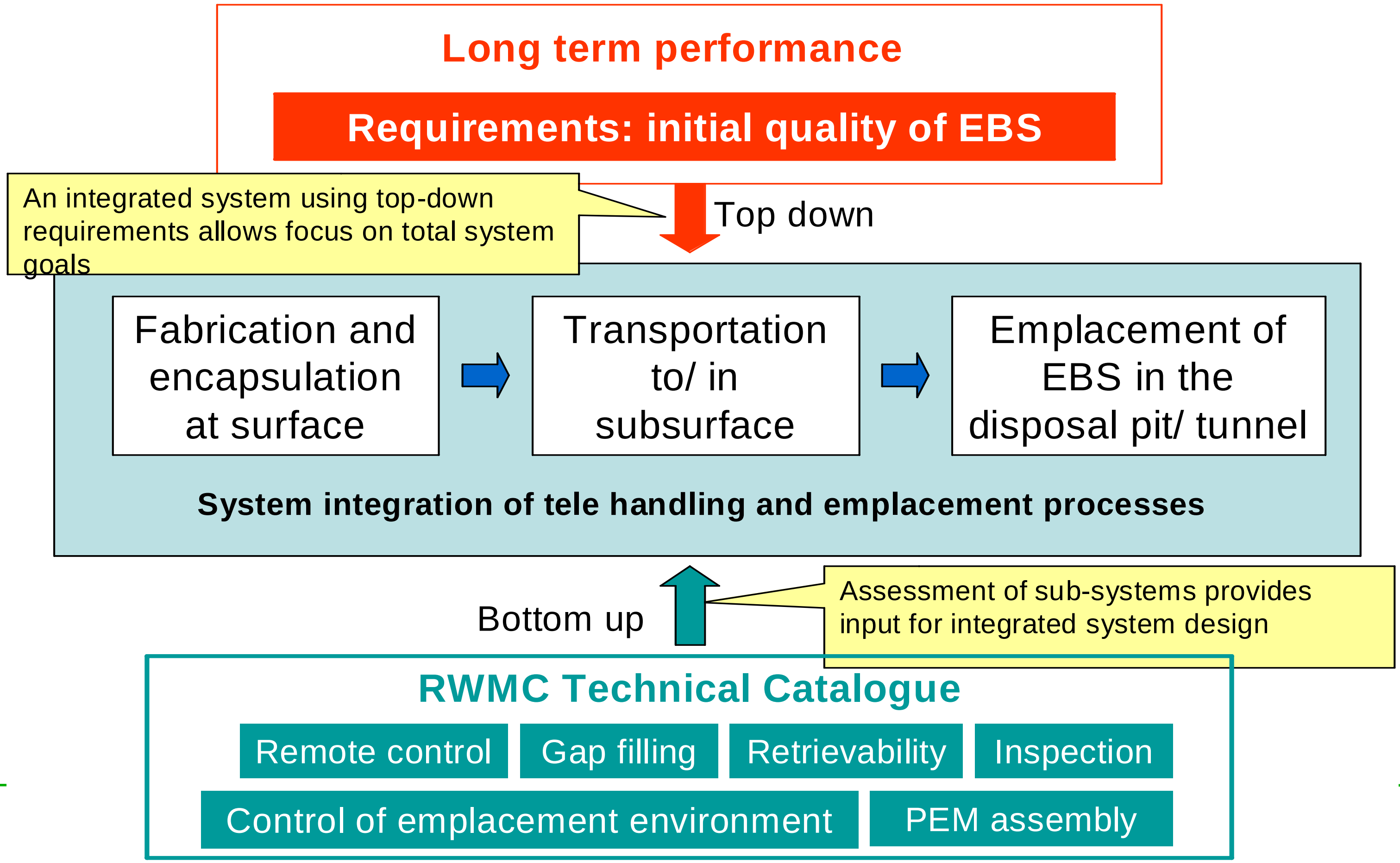
Stepwise move towards site-specific designs

- Although designs need to be as realistic as possible for operational analysis, the extent to which they can be tailored to sites will develop as the siting process proceeds

	LS Stage (PI selection)	PI stage (DI selection)	DI stage (Site selection)	Licensing stage
Construction & Operation	Only very superficial analysis	Operational scenarios which influence post-closure safety Site-specific construction / operational risks	All scenarios which influence post-closure safety (site specific). Scenarios for construction / operation safety case	All scenarios which influence post-closure safety (layout specific) Scenarios for construction / operation safety case
EBS	Based on H12 (HLW only) Qualitative discussion of divergences (particularly in terms of geometry, additional components)	Realistic base case with consideration of all major design components (HLW: maybe simplified for TRU) Quantitative analysis of major perturbations	Realistic base case with consideration of all design components (HLW & ?TRU) Quantitative analysis of all significant perturbations	Realistic base case with all components and reference layout (HLW & ?TRU) Quantitative analysis of all significant perturbations
Geosphere	Based on H12 Main focus on boundary conditions for EBS assessment Simplified site-specific transport of RN	Base case site-specific, as realistic as possible Full assessment of perturbations to EBS and FF RN transport	Base case realistic (site specific) Full assessment of perturbations to EBS and FF performance	Base case realistic (layout specific) Full assessment of perturbations to EBS and FF performance
Biosphere	H12-based, stylised but related to site location in terms of materials fluxes and standard lifestyle	Site-specific, realistic base case Alternative stylised scenarios appropriate to site	Site-specific, realistic base case Range of alternative stylised scenarios appropriate to site	Site-specific, realistic base case Range of alternative stylised scenarios appropriate to site
External perturbations	Site-specific, with focus on geological disturbances	Site-specific, considering all geological, climatic, anthropogenic, ... perturbations	Site-specific, considering all geological, climatic, anthropogenic, ... perturbations	Site-specific, considering all geological, climatic, anthropogenic, ... perturbations
Supporting arguments	Very general, analogues for site and EBS stability: laboratory demonstrations.	Site- and concept-specific, analogues for geological and EBS stability; local fluxes. Full-scale demonstrations	Set of supporting arguments for all main SC components (analogues, natural fluxes, etc.). Full-scale, long term demonstrations (post-closure).	Comprehensive set of supporting arguments for all main SC components. Full-scale, long term demonstrations (operational and post-closure).
Closure & monitoring	General closure concept (H12 base): baseline monitoring plan	Site specific closure concept, extended baseline monitoring plan (URL), general monitoring concept.	Site specific monitoring & closure concepts, outline baseline monitoring plan (construction & operation), response concepts.	Site specific monitoring & closure concepts: baseline monitoring and response plan (construction & operation).
Coupling between sites	Little Š medium (possibly none if few sites)	Medium - high	Very high	None (formally) Š but selection process may be needed to support SC /SEA

An integrated design process

- Design is a complex process requiring integration of top-level requirements - as specified, in particular, by long-term safety assessment - with working level practical constraints set by the individual steps that need to be carried out in a difficult working environment



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Conclusions and future requirements

- Repository design is moving from an early idealised phase into one focusing on operational practicality and safety
- Although long term safety is a key concern, in real life there must be trade-offs with other operational constraints
- In order to make decision-making more transparent, an expanded Safety Case definition could be useful
- A toolkit has been developed to aid choosing between design variants; nevertheless, this needs to be supported by practical experience gained in realistic, full-scale experiments, which should be a priority for the future

Acknowledgements

This paper is based on concepts developed during a number of projects including Alternative Repository Concepts / Remote Handling (supported by RWMC) and HLW Repository Concept Catalogue (supported by NUMO).