Strategy of conceptual model development based on site characterisation

A JAEA Workshop on
"Developing practical approaches to assess geological structures influencing repository design and performance assessment"

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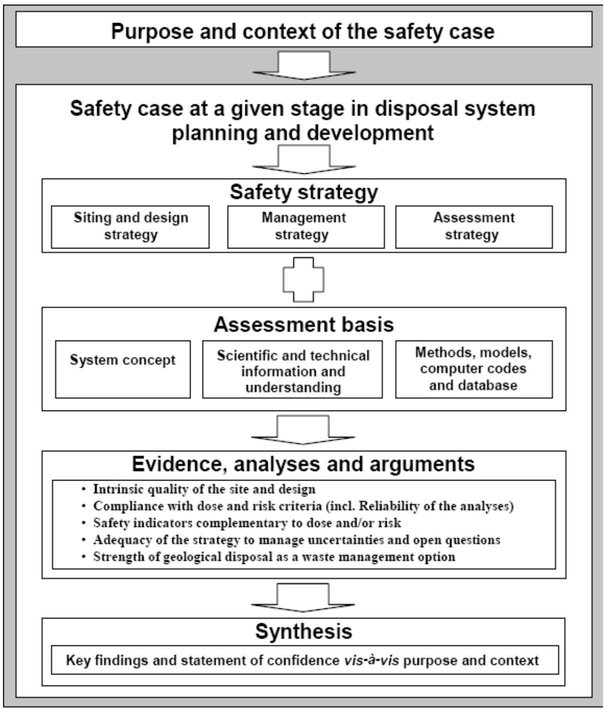
International context

- Development of some kind of SDM is now accepted as a key component of site characterisation: the expectations of such a SDM has, however, increased dramatically over the last decade (**NB terminology is not standardised**)
- In the '90s simple 2D or 3D models focused on structural geological data, possibly combined with a simple representation of hydrogeology and hydro-geochemistry. Although used to plan future characterisation activities, the SDM was mainly a representation of current site understanding (including past evolution)
- More recently, SDMs may include hyperlinks to any relevant datasets, so serve as a convenient access interface for site data. Such hyperlinks can include dynamic 3D model overlays (e.g. stress field evolution, groundwater flow, solute transport)

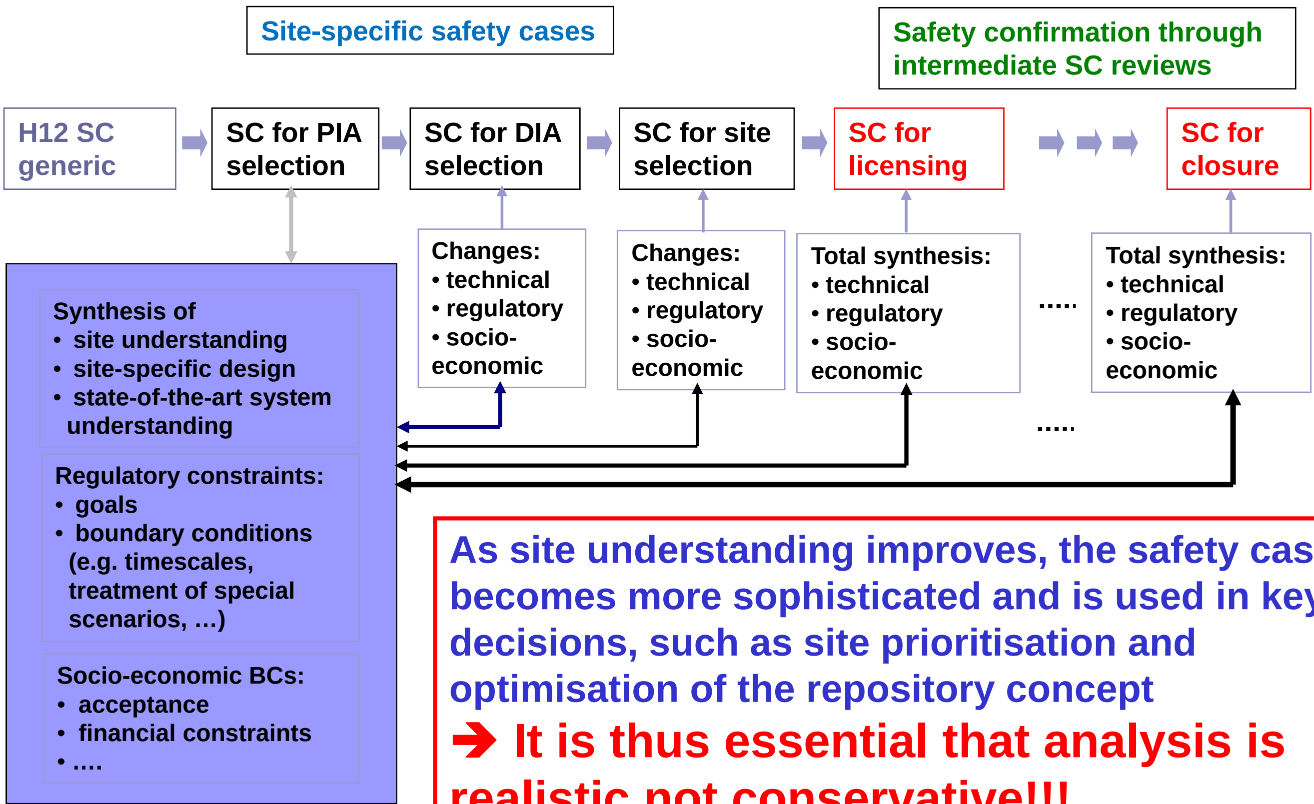
Safety Case components

- General consensus that:
  - **Boundary conditions are specific to national programmes and change with time**
  - **Safety strategy also varies between programmes**
  - **Early focus on post-closure safety was OK for generic feasibility demonstration, but a wider context has to be examined when projects become site-specific and move closer to licensing**



(NEA, 2004)

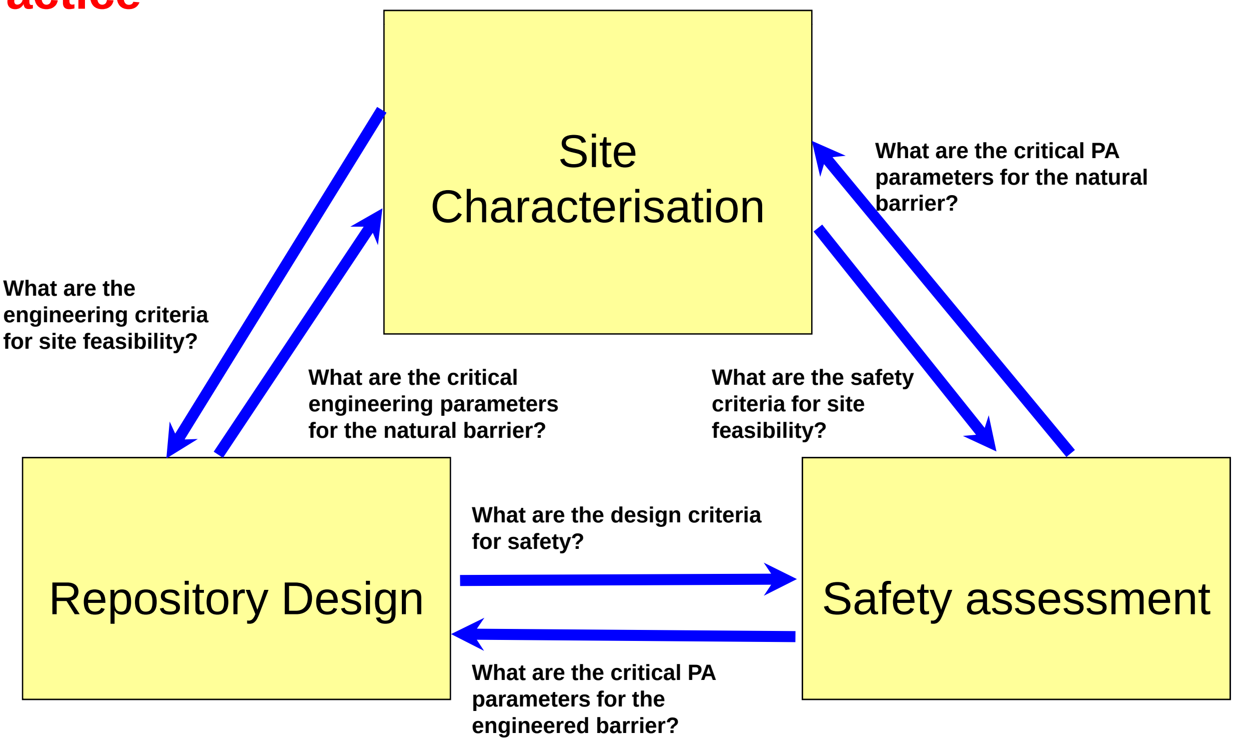
Stepwise evolution of the Safety Case



As site understanding improves, the safety case becomes more sophisticated and is used in key decisions, such as site prioritisation and optimisation of the repository concept

➔ **It is thus essential that analysis is realistic not conservative!!!**

Coupling site characterisation / repository design / safety assessment:
Easy to say in principle, difficult to implement in practice



General framework for linkage of SC/RD/SA

Boundary conditions (technical, legal, socio-political, …)	Requirements	Requirements	Requirements	Requirements
Check against BCs and address issues by ...egration into safety case	**Site characterisation**	SDM	SDM	SDM
Check against BCs and address issues by ...egration into safety case	Feed back to site characterisation plan	**Selection of repository concept**	Repository concept	
Check against BCs and address issues by ...egration into safety case	Feedback to site characterisation plan	Feedback to select options if needed	**Design work**	Repository design
Check against BCs and address issues by ...egration into safety case	Feedback to site characterisation plan		Feedback to design	**Operational SA** / **Post-closure SA**

Experience to date

- Site models - only as good as site understanding!
  - The history of geological disposal is full of examples of major surprises due to lack of site understanding - and overinterpretation of existing knowledge
  - They have often been costly and can cause loss of credibility in the implementing organisation
- In retrospect, problems were often not spotted (or spotted too late) due to:
  - over-confidence in the interpretation of field data (especially geophysics)
  - lack of synthesis of information from different fields of earth science
  - focus on a single model, rather than presenting a series of alternatives
  - poor understanding of errors and uncertainties in measurements

SDM evolution

- Should be a “live” interface to the geodatabase, which facilitates presentation of interpretations and interpolations / extrapolations (in both space and time)
- Should facilitate cross-discipline communication and checks of internal consistency (e.g. structures, hydrogeology, hydrochemistry, isotope hydrology,...)
- Should allow alternative interpretations to be accessed
- Should be interfaced (or, at least, hyperlinked) to repository design and PA models
- Must show errors and uncertainties in data and sub-models: with rigorous calculation of uncertainty propagation, if appropriate

Identified challenges

- Autonomic input of streaming data during site characterisation to allow updating in real time and direct feedback to tailor the characterisation programme
- Introduction of time element to allow representation of the understanding of past evolution of the site and expectations (or scenarios) of future evolution
- Direct interfacing with repository designs to facilitate tailoring to site characteristics and rigorous comparison of options
- Direct integration with performance assessment codes to provide traceability of site characteristics used and facilitate communication between geologists, design engineers and performance assessors
- Rigorous QA & representation of uncertainties: a critical feature essential to all the points noted above, but not always included or functional…..

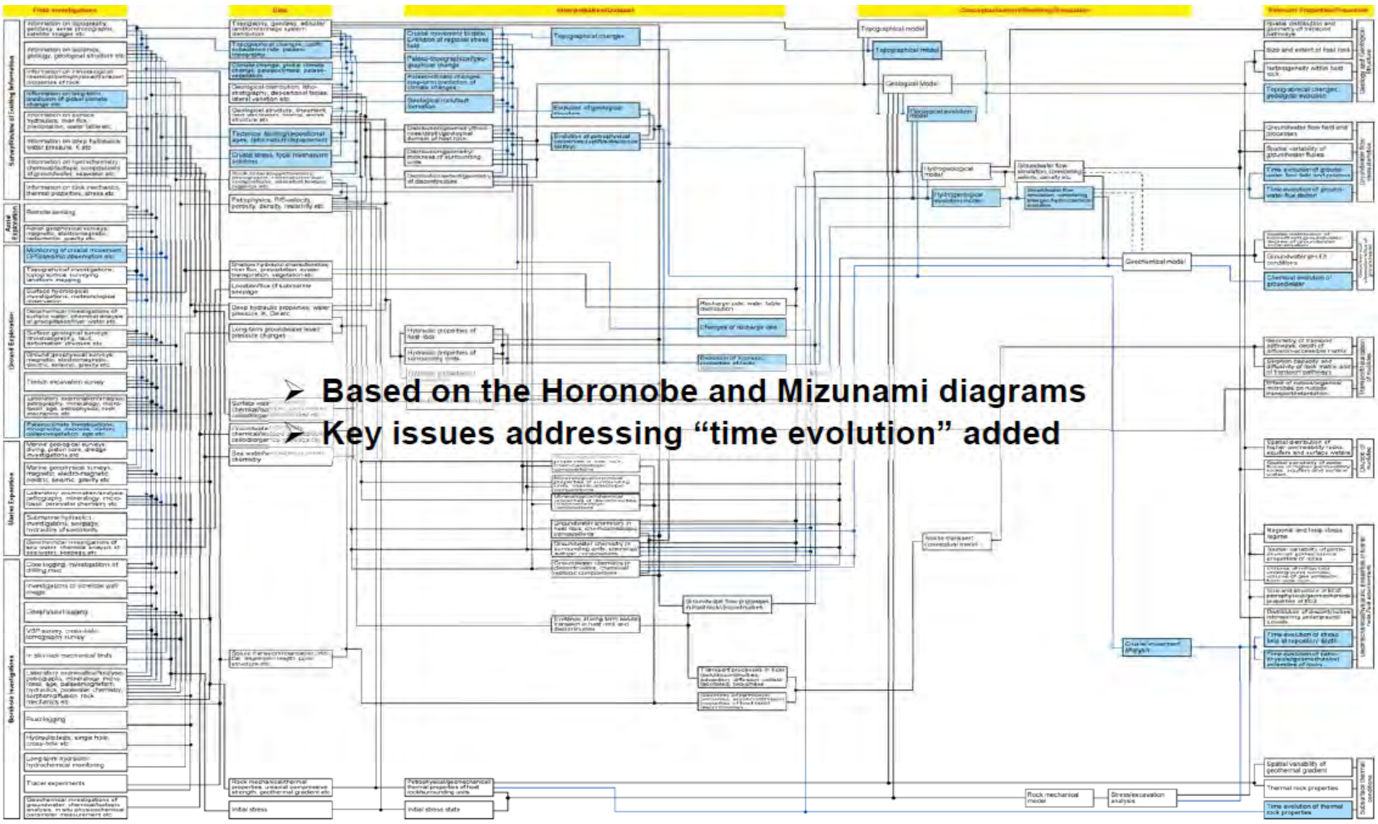
JAEA challenge for SDM development

- The capacity of geosynthesis is expanding rapidly, with JAEA in the lead in terms of introduction of smart software to contribute to making the process faster and more interactive - which allows more functionality to be included in the SDM

Process qualification

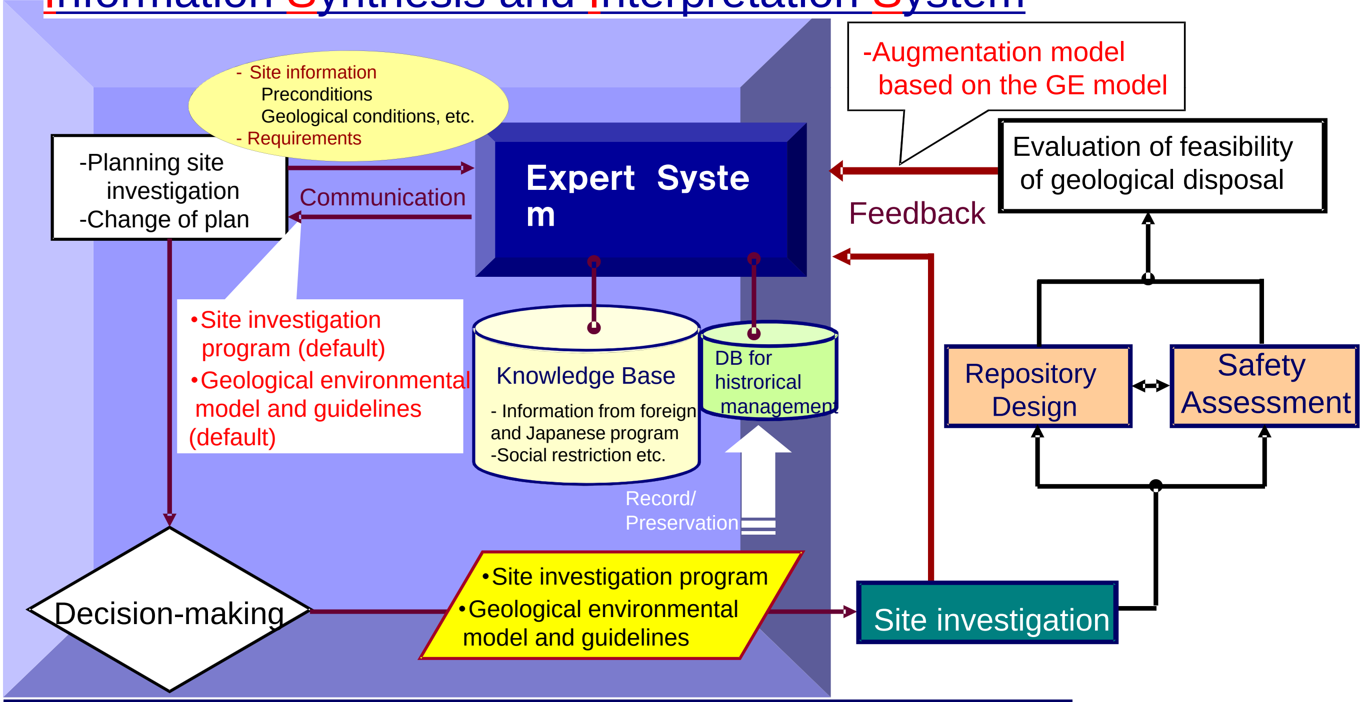
- In the staged implementation process, the boundary conditions for each safety case will be different and hence the details of the process will change
- Focus should thus be on general principles that ensure quality to a level that is “fit for purpose”
- This is difficult to define in advance – but might be facilitated by use of some of the KMS tools currently under development by JAEA
  - A starting point might be identification of past problems…

JAEA Formulation of “Synthesis Data Flow Diagram” for Coastal Site Characterisation



Basic Concept of ISIS

Information Synthesis and Interpretation System



Variable boundary conditions

National program/law, Requirement of site selection, Guidelines, Costs/Time, Agreement with local community, Geological environment conditions, Surprises, Impact on environment etc.

Iteration of analysis (SD modelling ➔Planning➔ Investigation)

Analysis of know-how/desicion-making process on SDM construction

- Geology
- Hydrogeology
- Geochemistry
- Rockmechanics
- Thermal property
- Mass transport
- Biosphere

Analysis of know-how/desicion-making process on planning

- General planning
- Individual planning
  - ✓Surface geophysics
  - ✓Borehole investigations

Analysis of know-how/decision-making process on investigation, modelling/simulation

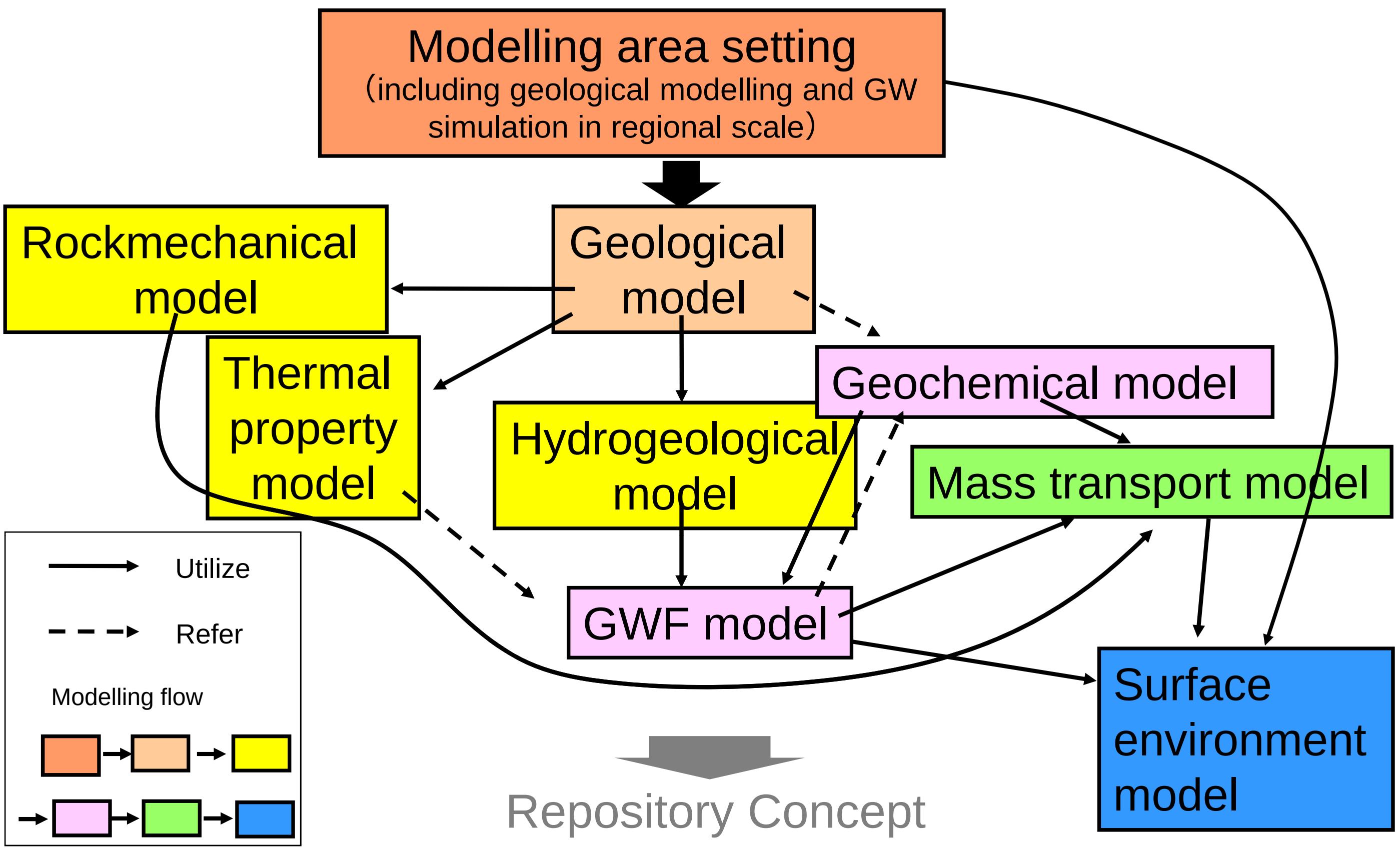
- Borehole investigation
  - ✓Hydraulic testing
  - ✓GW sampling
  - ✓Estimation of GWchemistry distribution
- Modelling & simulation・・・

Important site factors & data requirements

- Based on the requirements from NUMO favorable factors
- View points of
  - Safety Assessment
  - Design/construction
  - Environmental impact

	Important factors to be characterized	Data requirements
Safety assessment	Geological structure	Size and geometry of host rock; heterogeneity within host rock
		Size and extent of surrounding formations
		Spatial distribution and geometry of transport pathways (groundwater flowpaths)
	Groundwater flow characteristics	Spatial variability of magnitude of hydraulic gradient
		Spatial variability of hydraulic properties of rocks
	Geochemical characteristics of groundwater	Redox conditions
		Spatial variability of groundwater pH values
		Spatial distribution of different groundwaters; degree of groundwater mineralization
	Transport/retardation of nuclides	Sorption capacity and diffusivity of rock matrix and of transport pathways
		Geometry of transport pathways; depth of diffusion-accessible rock matrix
		Effect of colloid/organics/microbes on nuclide transport/retardation
	Dilution of nuclides	Spatial distribution of higher-permeability rocks, aquifers and surface waters
		Spatial variability of water fluxes in higher-permeability rocks, aquifers and surface waters
Designing & construction of underground facilities	Geomechanical/hydraulic properties of tunnel near-field environment	Local stress regime
		Spatial variability of petrophysical/geomechanical properties of rocks
		Volume of inflow into underground tunnels
		Size and structure of EDZ; petrophysical/geomechanical properties of EDZ
		Distribution of discontinuities intersecting underground tunnels
	Subsurface thermal conditions	Spatial variability of geothermal gradient
		Thermal rock properties
Environmental assessment	Environmental impact induced by construction of underground facilities	Impact on water table
		Impact on hydraulic pressure
		Impact on groundwater chemistry
		Effects of noise and vibration

General procedure for SDM

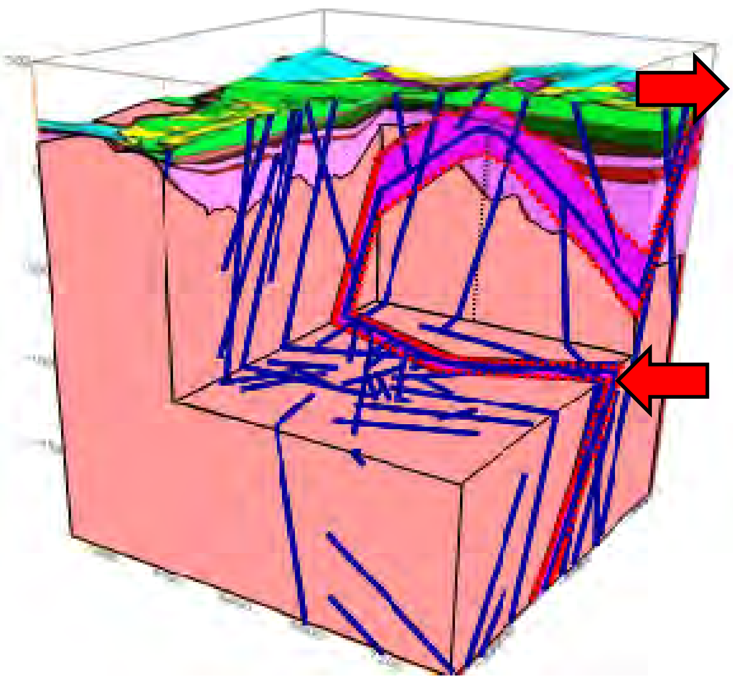


QA – site representation

- Rigorous QA is essential to allow the resultant SDM to be used to support development of a safety case which will be the basis of site selection and eventual move towards licensing
- Indicators of QA problems:
  - Limitations of use of idealised site conceptual models which focus entirely on post-closure safety not emphasised
  - Limited emphasis on fundamental limitations of the characterisation process (especially during LS and PI phases)
  - Mixture of conservative and non-conservative assumptions that make assessment of safety margins difficult
  - Highly idealised (unrealistic) models of the RN transport pathways and, especially, GBI

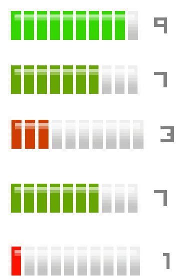
SDM(0) - example

- Mouse access on rotatable 3D visualisation of SDM



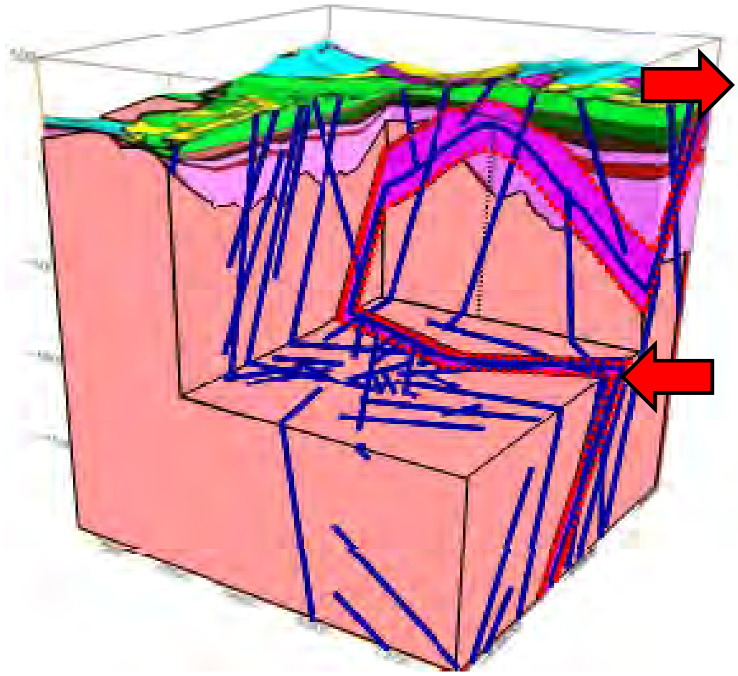
Current understanding

Structure
Rock Mechanics
Flow system
Hydrochemistry
Solute transport



SDM(-100ka)

- Menu to allow access to interpretation of past development…

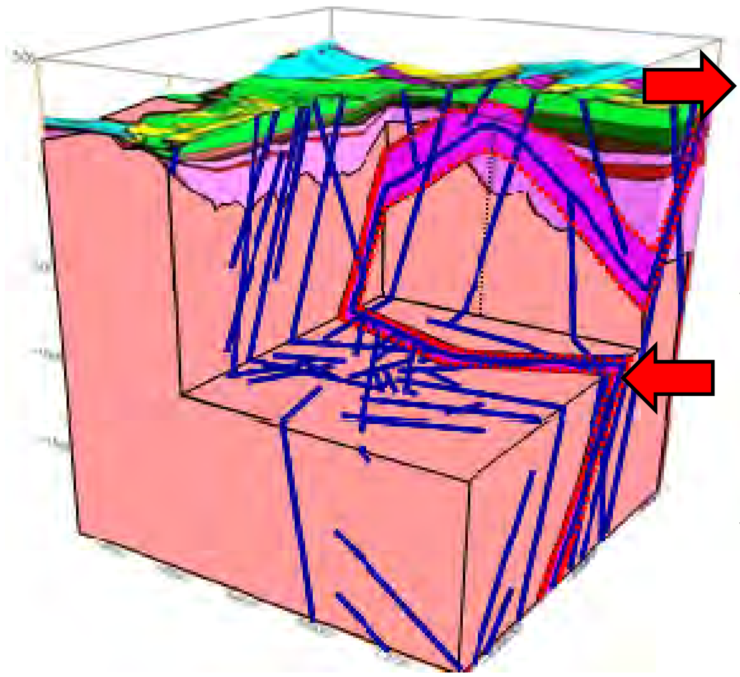


T = -100 ka

Structure	9
Rock Mechanics	7
Flow system	1
Hydrochemistry	3
Solute transport	1

SDM(+100ka)

- …and future evolution



T = +100 ka

Structure	7
Rock Mechanics	3
Flow system	1
Hydrochemistry	3
Solute transport	1

Typical knowledge needed - models

- Any model is an inherent simplification of a real system; the consequences of the simplification process must be understood:
  - Assuming processes are constant with time or undergo stepwise changes
  - Averaging or nesting models to allow spatial scales from sub-cm to many km to be represented
- Even if sub-models are well understood, combining models into chains must be done with care
- Some models can reasonably realistic, but others must be idealised (e.g. biosphere)
- An important area is taking into account inevitable uncertainties and balancing them by supporting arguments

Open questions remain, however...(I)

- The complexity and massive capabilities of the new tools should not obscure the fact that certain areas will always be problematic – and will require other forms of solutions. For example:
  - When are data/samples/boreholes enough? When our level of understanding/conceptual model does not change following each new sampling campaign? How can our sampling strategy reflect this fundamental uncertainty?
  - Explorability of many fractured rocks remains a problem (and is rarely discussed), despite novel tools and approaches
  - Understanding the past evolution of a site is a fundamental building block for predicting the future evolution – but this is often omitted in formal SDMs

Open questions remain, however...(II)

- Integration of the often disparate streams of data is the single biggest challenge and fundamental discrepancies can (and do) remain in the final SDM due to weaknesses in the review chain
- Remember: the presence of a QMS, including a review system, does NOT mean that no mistakes will be made
  - For example, it is essential to ensure that a strong Issue Resolution system is in place – and functions properly
- Remember: as deadlines loom and time pressure mounts, the first victim is almost always the QMS – and this must be avoided at all costs
  - For this, it is essential that upper management take QM seriously from the outset and ensure that the QM managers‘ powers of persuasion are backed by the full weight of the organisation (and are not just decoration added to keep the regulators happy)

Conclusions

- SDM development is one of the critical steps in site characterisation: past international experience has, however, been mixed
- The challenges associated with geosynthesis increase as the fluxes of information from modern characterisation tools and the sophistication of pre-processing technology increase at an exponential rate (roughly in line with Moore’s Law)
- Modern computer graphics provide a key for a user-friendly interface to the wide range of specialists involved - but can often lead to drastic over-interpretation of output
- To minimise risks of costly mistakes, it is essential that SDMs are based on QAd data and adequately represent all system uncertainties. Rigorous implementation of a QMS is a major challenge that has yet to be fully resolved in any national programme!