Performance Assessment

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Introducing the NNL – A UK Government Owned Contractor Operated (GOCO) Organisation

Department of Energy and Climate Change (DECC)

Shareholder Executive

NNL Ltd Board - Chair, 2 Non-Execs, 3 Execs

Management Contract

serco MANCHESTER 1824 Battelle The Business of Innovation

- Management Secondees
- Reach-back
- 3yr+1yr+1yr contract
- Deliver Strategic and Business Plans

Executive Leadership Team

National Nuclear Laboratory

Our heritage

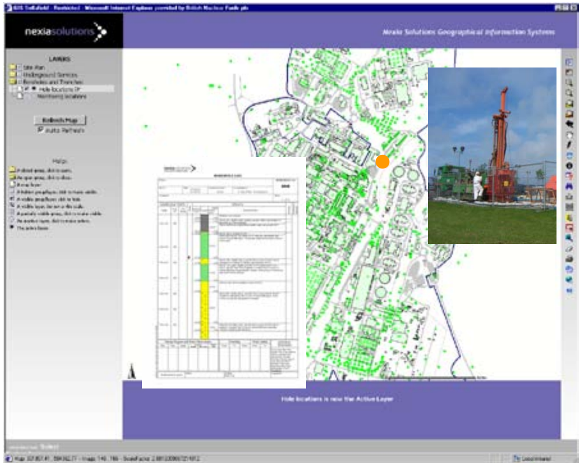
- 1954 – UKAEA formed to oversee the nation's nuclear research programme
- 1971 – BNFL formed
- 1996 – R&T division
- 1998 – Magnox integration
- 2003 – NSTS established
- 2003 – Acquired AEAT nuclear science business
- 2005 – Nexia Solutions Limited launched
- 2006 – UK Government announces intention to establish National Nuclear Laboratory, based around Nexia Solutions
- 2008 – NNL formed

NNL Environmental Capability

- Provides a broad and comprehensive range of technical services covering all aspects of nuclear site operations.
- Extensive experience of working and delivering in a tightly regulated environment

Capabilities and expertise includes:

- Contaminated Land Assessment and Remediation
- Site Characterisation and monitoring
- Environmental risk assessment/Environmental safety cases
- Radioactive waste management and disposal
- Regulatory Permissioning
- Effluent treatment



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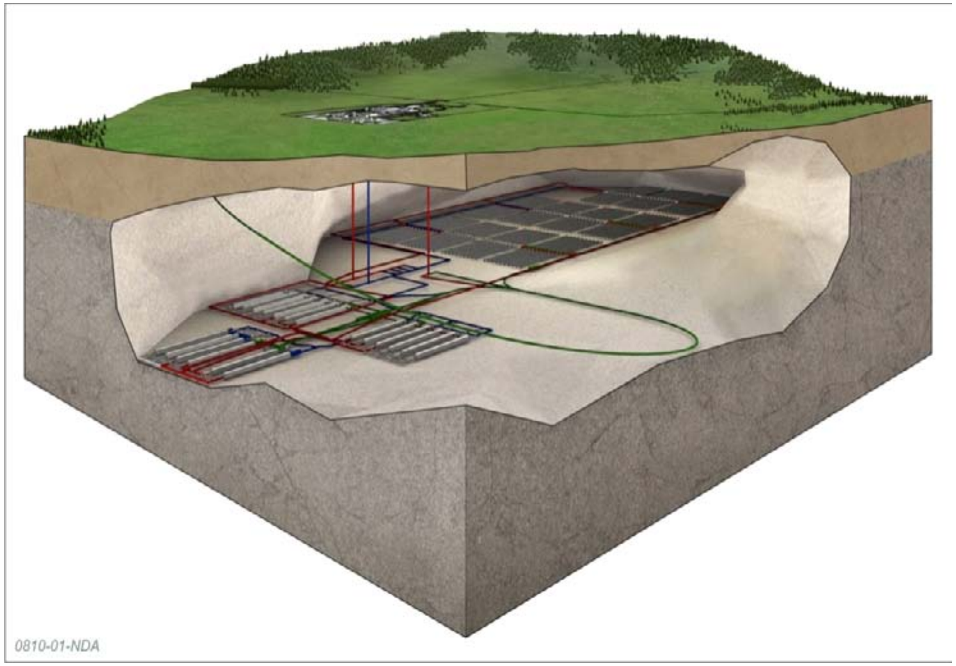
Presentation outline

- Geological Disposal Facility (GDF)
- Safety Case and performance assessment
- Regulatory Context
- Performance assessment process
- Representation of radionuclide behaviour in performance assessments
- Examples
- Summary

Geological Disposal Facility

- A site has been selected for a GDF
- What needs to be considered in order to operate the facility
  - Understanding of the wastes
    - Level of characterisation
    - Have they been treated?
    - How have they been packaged?
  - An authorisation process needs to be undertaken
    - Safety assessment
    - Safety Case



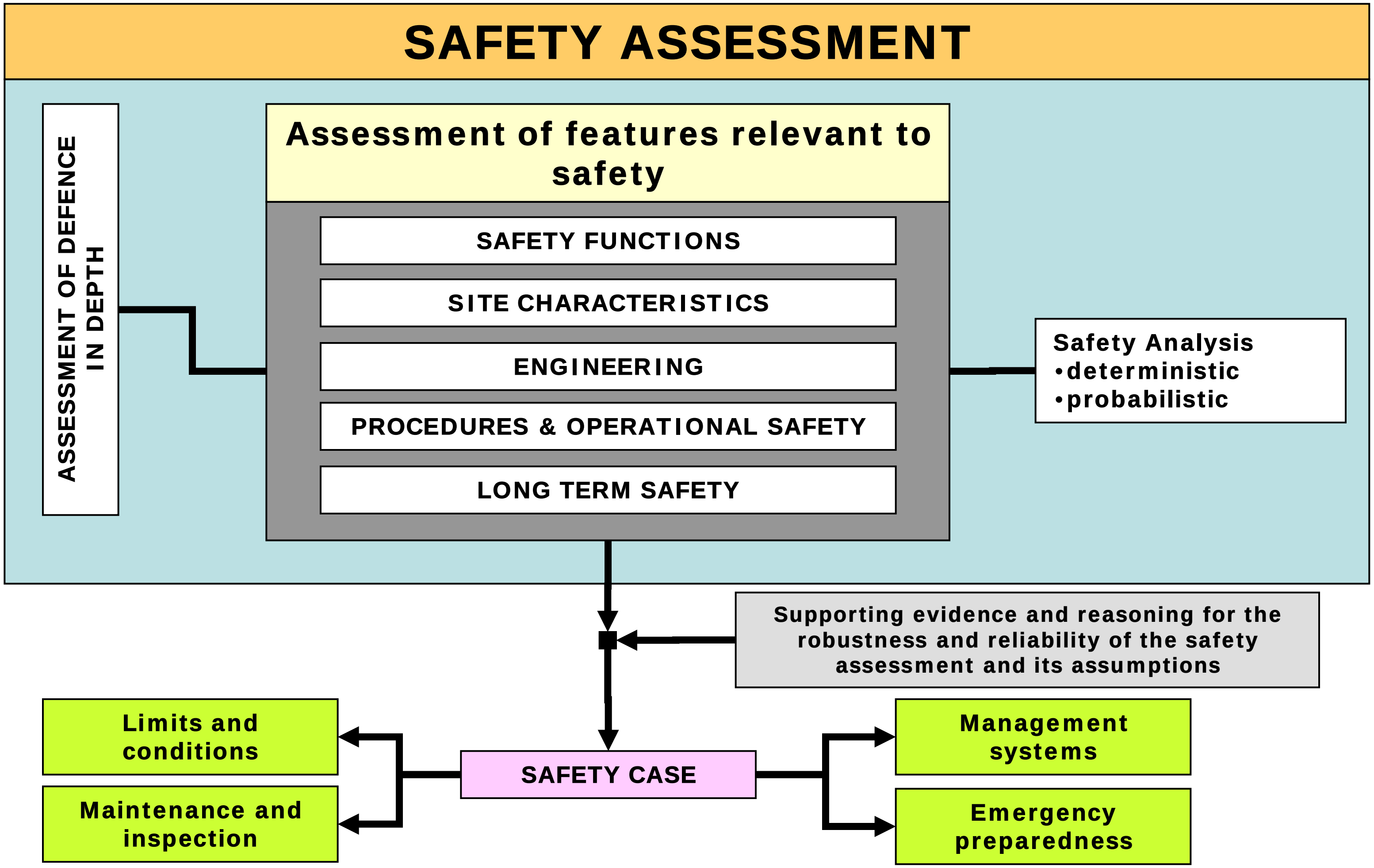
Some definitions (1)

*"**Safety assessment** is the evaluation of long-term performance, of compliance with acceptance guidelines and of confidence in the safety indicated by the assessment results"*

*"A **safety case** is a collection of arguments, at a given stage of repository development, in support of the long-term safety of the repository. A safety case comprises the findings of a safety assessment and a statement of confidence in these findings. It should acknowledge the existence of any unresolved issues and provide guidance for work to resolve these issues in future development stages"*

NEA, 1999

The safety case and safety assessment

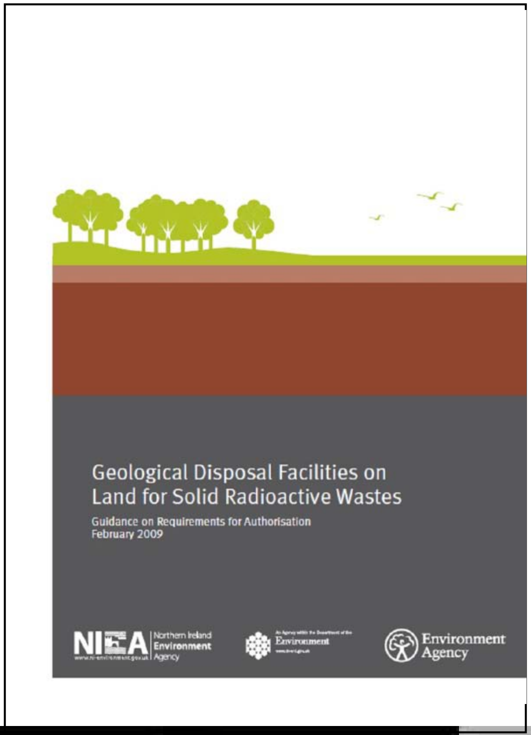


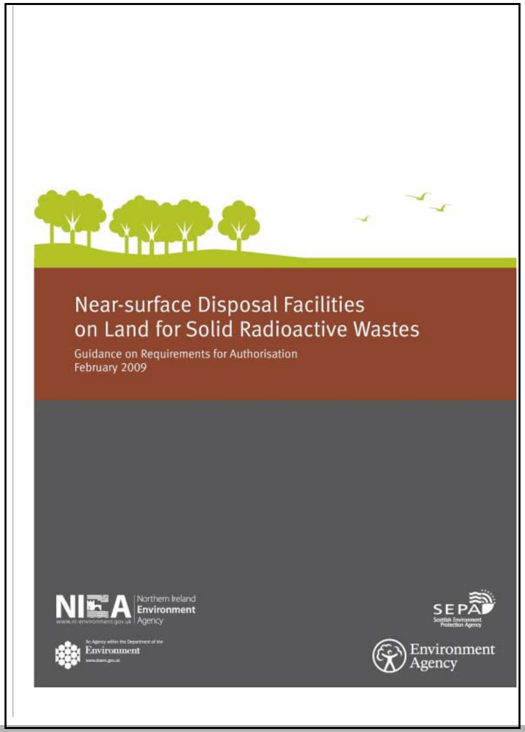
The safety case and safety assessment

- Periods of concern:
  - Pre-operational period:
    - Site selection, design and construction of the disposal facility
  - Operational period:
    - From site development until closure
  - Post-closure period:
    - Begins the moment the site is closed
      - Institutional control period (control disposal site and its use)
      - Post-institutional control period (controls no longer in place)

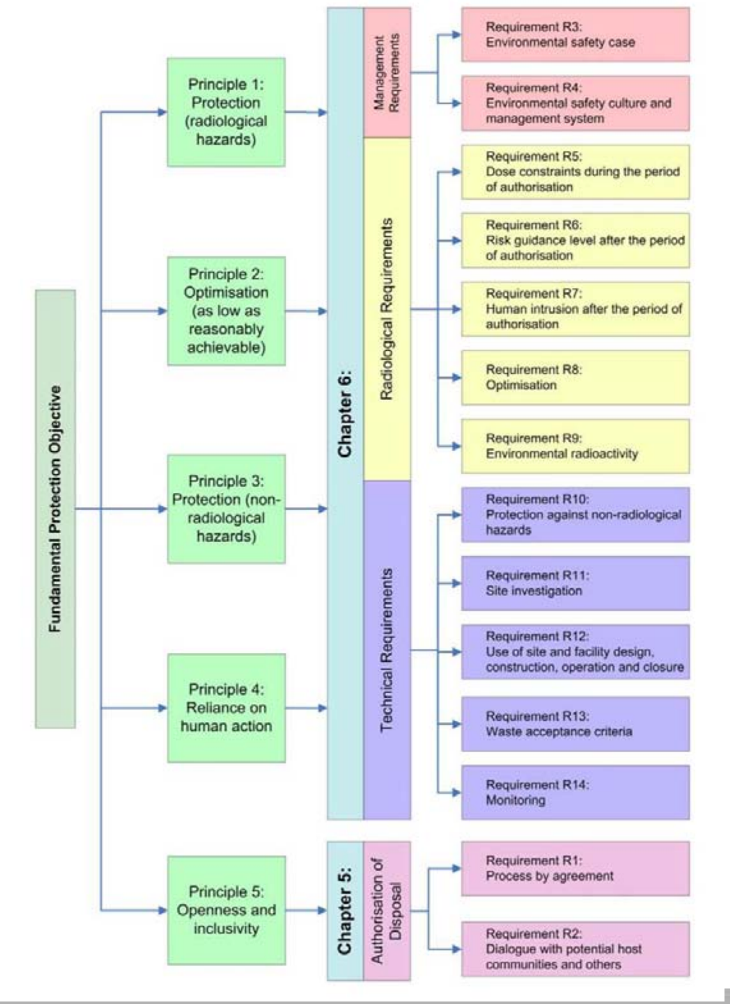
UK Regulatory Context

- Guidance on Requirements for Authorisation. New version issued 2009 - replaced version issued 1997





Principles and requirements

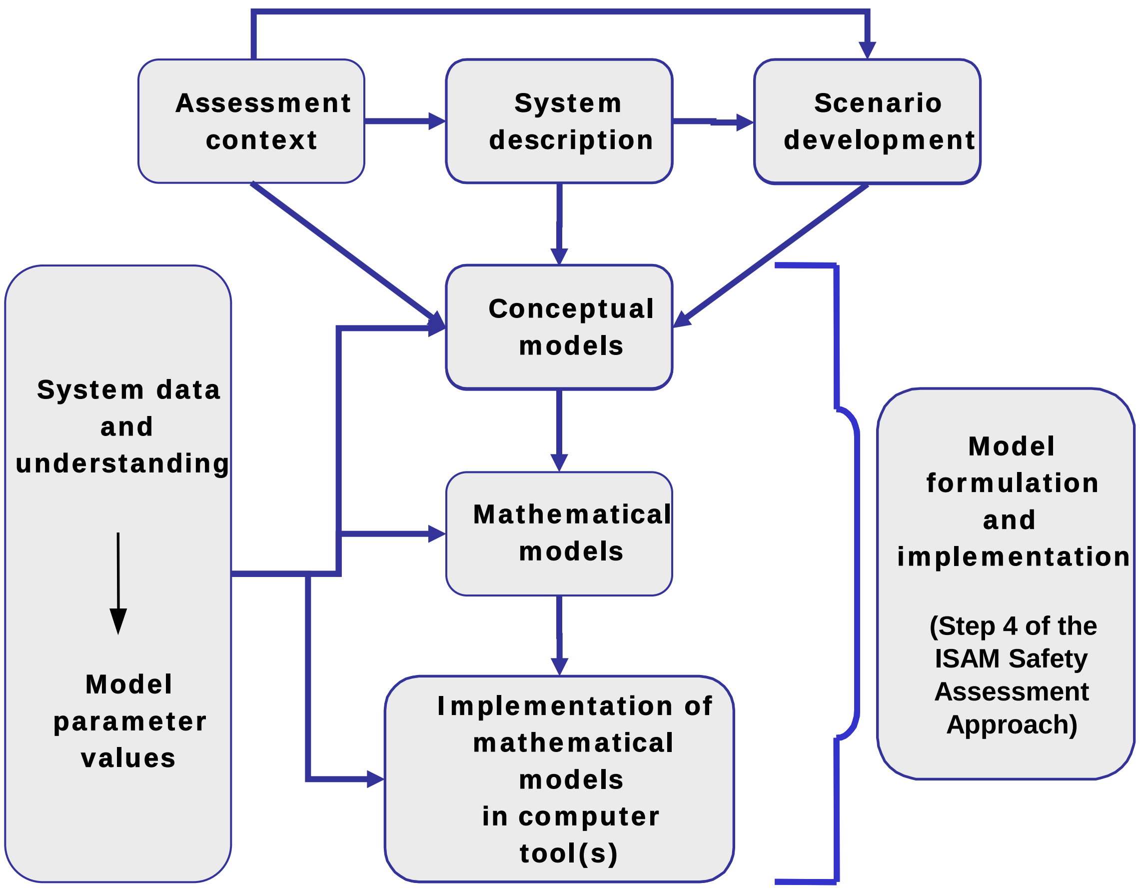


Key features

- High level key features of a PA include
  - aimed at synthesising system understanding
  - based on underpinning studies (eg site characterisation research, modelling),
  - involves the development and use of (highly) simplified models of reality (“total system model”)
  - these models are used as tools to analyse system performance in support of decision making / or demonstration of meeting regulatory requirements
- Scope and detailed methodology is highly dependent on the “*assessment context*”

Assessment process

IAEA ISAM Model development and implementation process

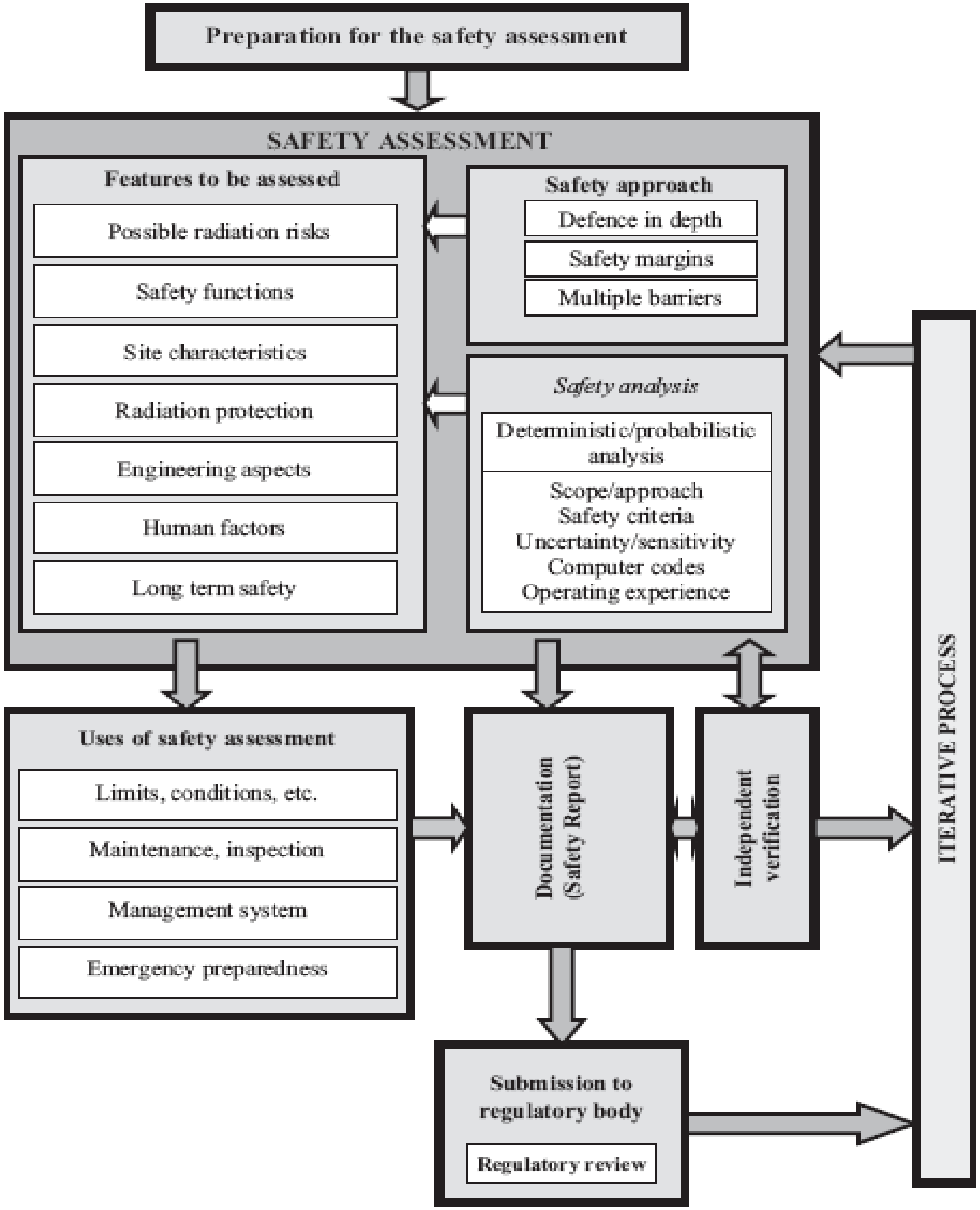


Assessment context

- The purpose of the assessment (eg to support Safety Case)
- The regulatory framework / criteria (eg GRA)
- Facility / site management assumptions (eg facility design, institutional control)
- Assessment end points (eg: dose/risk, flux, environmental concentrations, receptors considered, rad vs non-rad contaminants)
- Assessment philosophy (eg: realism vs conservatism, treatment of uncertainty)
- Previous iterations of the assessments
- Timeframe

Example showing linkages between the assessment process and factors that are determined by the assessment context

(IAEA, 2009)

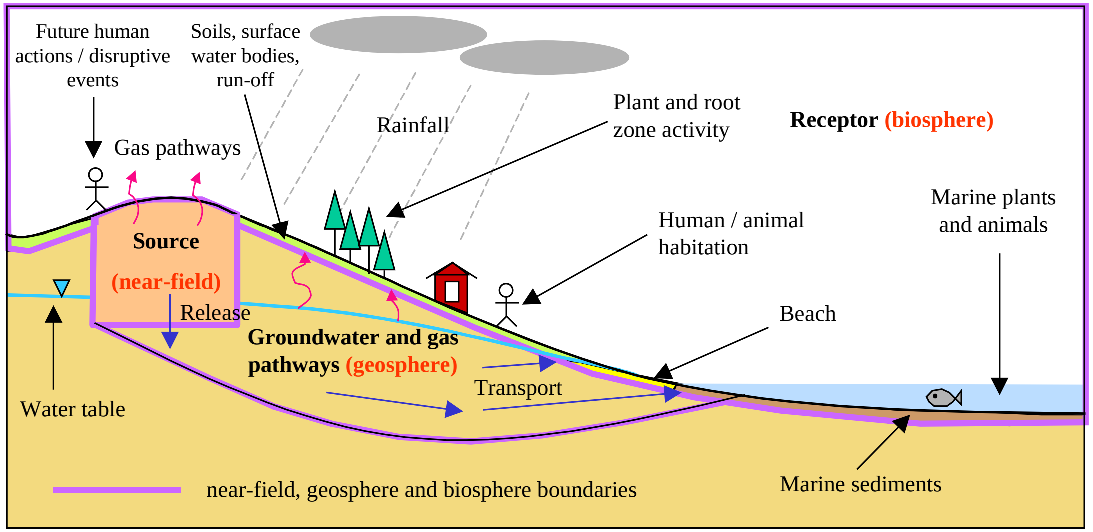


System description - Pollutant linkages

- Assessments generally based on a Source-Pathway-Receptor (S-P-R) model
  - Source: Release function (eg leaks and leaching from waste)
  - Pathway: Means by which released activity is transmitted to Receptor (eg. transport within near field and geosphere, transfer between biosphere 'compartments', exposure pathways, eg inhalation or ingestion)
  - Receptor: environmental media, humans (depends on assessment context)
- Pollutant linkages comprise the S-P-R relationships, i.e. the means by which a contaminant may impact a receptor
- Without a valid S-P-R linkage, there can be no risk
- System description entails the identification and characterisation of most important S-P-R linkages

System description

- Description of the disposal system:
  - Near field (Source / Pathway)
  - Geosphere (Pathway)
  - Biosphere (Pathway / Receptor)
- Points to consider:
  - Ensure documentation of relevant characteristics of multi-barrier system on which long-term safety relies.
  - Balance between qualitative / quantitative descriptions for input to assessment models.
  - Importance of maintaining clear audit trail for documentation of key assumptions and associated uncertainties.
  - Level of detail should be appropriate to assessment context.

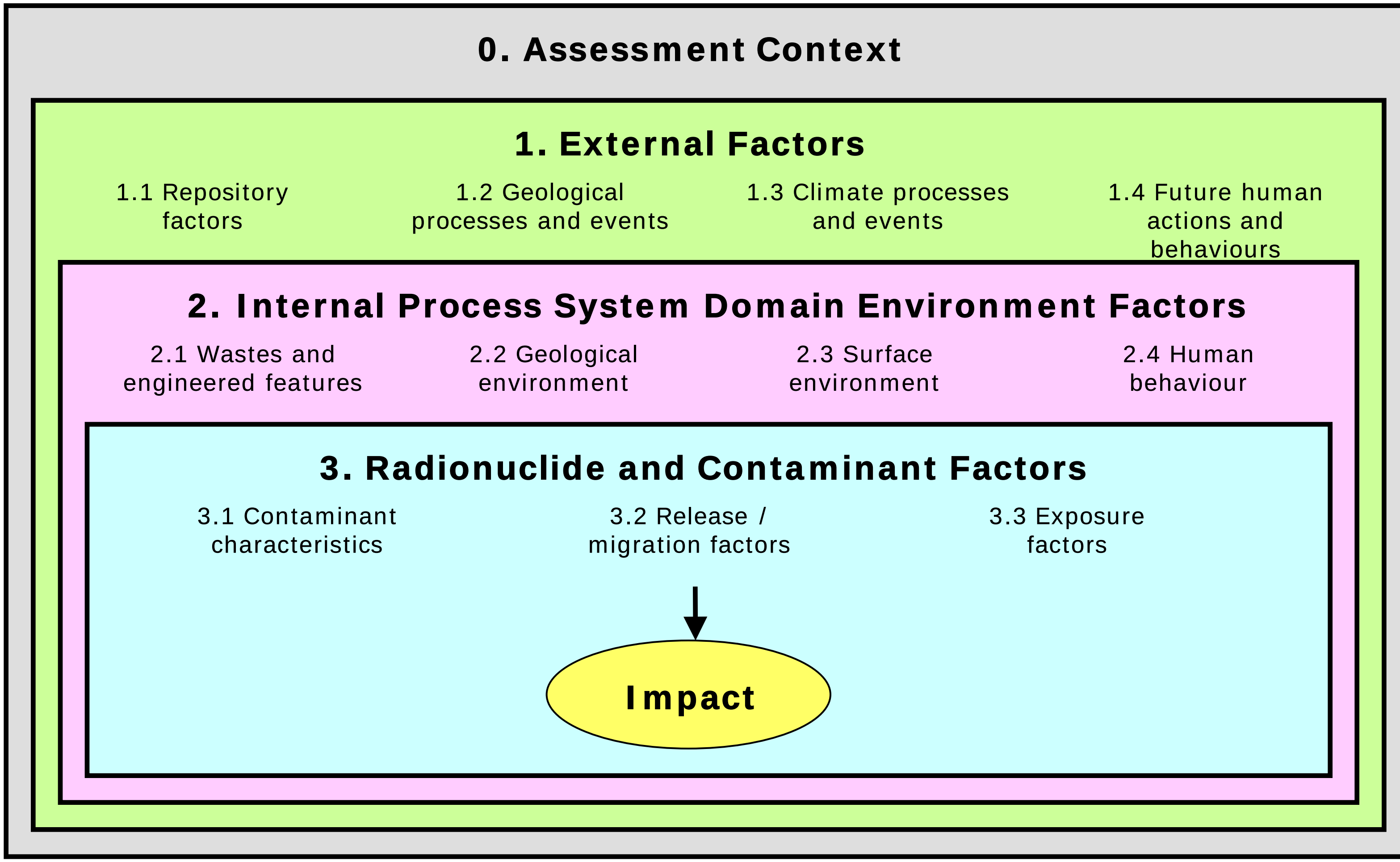


Scenarios (1)

- In order to assess disposal system performance, a variety of different factors need to be evaluated in a consistent way, often in absence of quantitative data.
- Typically achieved through formulation and analysis of a set of scenarios:
  - *A scenario is a broad description of the evolution of the disposal system and its surroundings as a result of natural, human induced, waste-related and engineering-related events and processes.*
- Initial stage in scenario construction – compilation of comprehensive list of features, events and processes (FEPs) that could directly or indirectly influence the disposal system and the fate and transport of radionuclides within it.
- Commonly done through screening international FEP list (e.g. IAEA ISAM, NEA).
- Scenarios may be assessed qualitatively or quantitatively.

FEPs

ISAM FEP list



Source and treatment of uncertainties

- Sources of uncertainty include
  - ➢Parameter uncertainty (eg due to incomplete data)
  - ➢ Conceptual model uncertainty (eg due lack of knowledge of future state of system
  - ➢ Model uncertainty (eg ‘numerical dispersion’)
- PA needs to take account of these uncertainties
- This is achieved by
  - ➢Multiple conceptual models and PA model implementation (eg to account for various potential groundwater pathways)
  - ➢Multiple scenarios and calculation cases (eg modelling of various climate states, or barrier degradation scenarios)
  - ➢ Sensitivity analysis
  - ➢ Probabilistic modelling approaches (eg Monte Carlo analysis of selected parameters)

Scenarios (2)

- Scenario development and justification:
  - Reference Scenario:
    - Initial consideration
    - Often considered to be the most likely scenario
    - Benchmark scenario to compare impact of alternative scenarios
    - Normal evolution scenario, design scenario, base case scenario
  - Alternative Scenarios:
    - Investigate impact of scenarios different from reference scenario
    - Sensitivity analysis of reference scenario
    - Altered evolution scenario, deteriorated evolution scenario
  - Methodologies for scenario development:
    - Systematic methodologies (geological and near-surface disposal systems)
    - None of them claimed to be only or best one

Scenarios – Yucca Mountain Example

Four scenario classes divided into seven modeling cases

Nominal Scenario Class

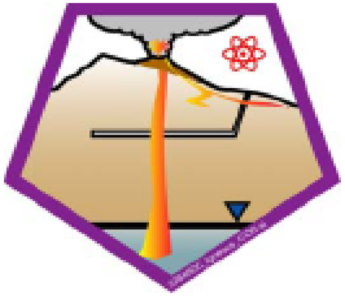
- Nominal Modeling Case (included with Seismic Ground Motion for 1,000,000-yr analyses)

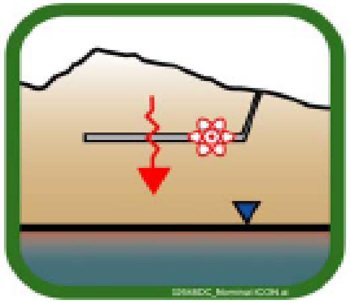
Igneous Scenario Class

- Intrusion Modeling Case
- Eruption Modeling Case

Early Failure Scenario Class

- Waste Package Modeling Case
- Drip Shield Modeling Case





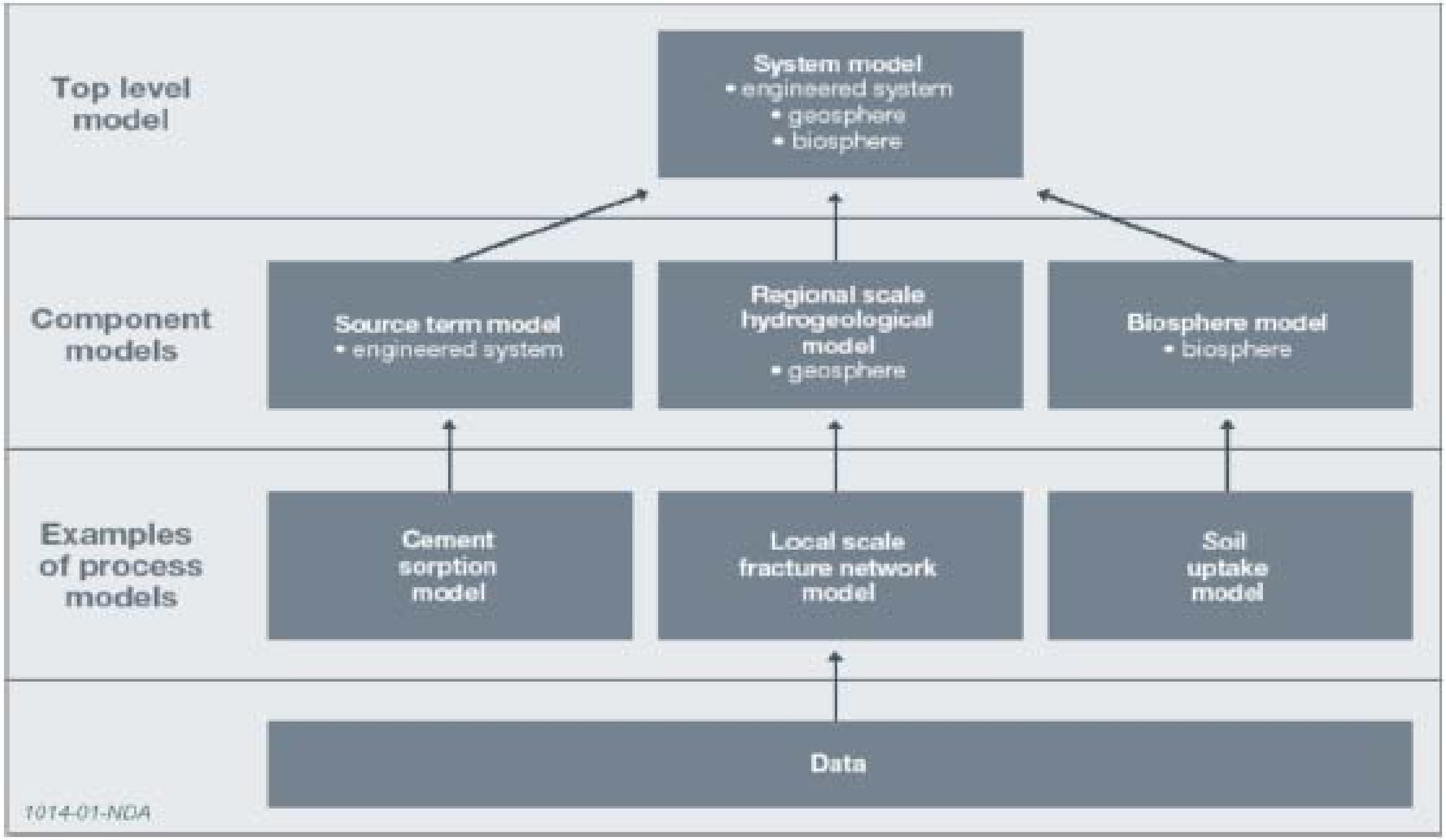
Seismic Scenario Class

- Ground Motion Modeling Case
- Fault Displacement Modeling Case

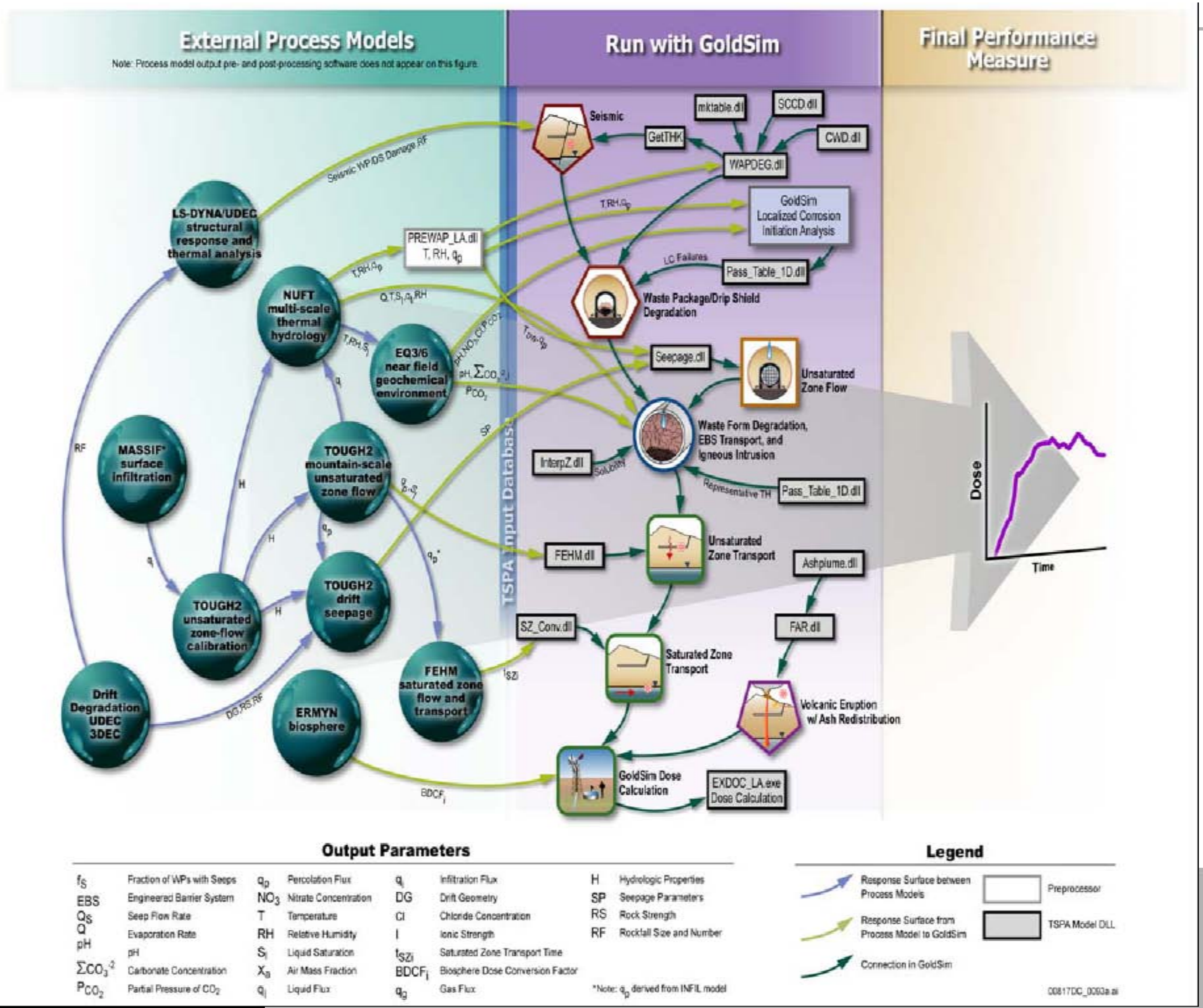
Assessment models

- Purpose:
  - Assess consequences of scenarios in terms of assessment context and system description
- Requirement:
  - Formal, defensible and transparent to independent review
- Three stages:
  1. Generate conceptual models of disposal systems using information from assessment context, system description and scenario generation
  2. Represent conceptual models and associated processes in mathematical models
  3. Implementation of mathematical models in computer codes
- Considerations:
  - Type of model, e.g. detailed or assessment level
  - Available computer codes
  - Treatment of uncertainty, e.g. deterministic or probabilistic

Example: models used in the 2010 PCSA by NDA

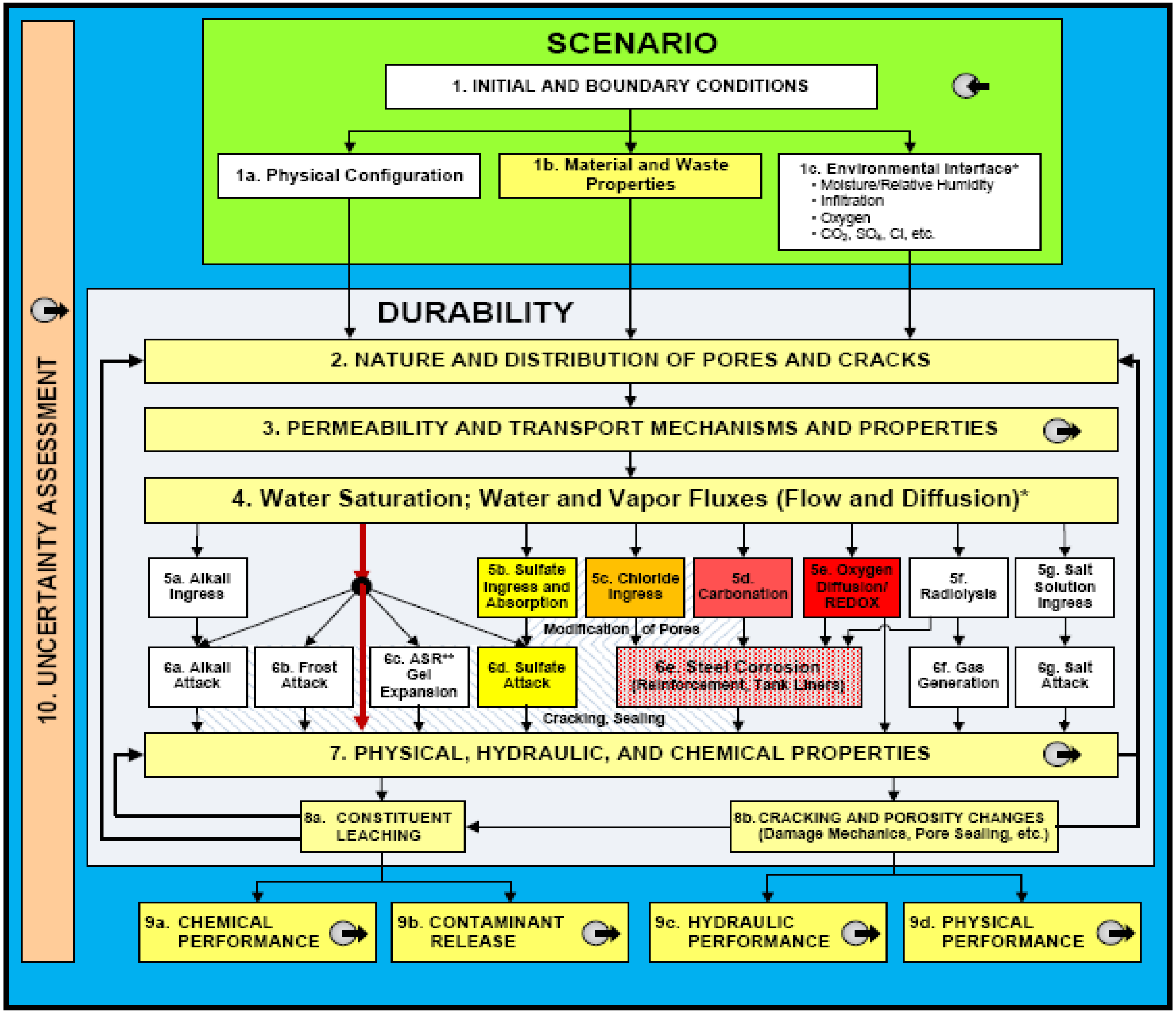


Example: models used in TSPA for Yucca



PA model integration example: CBP (2)

Specifications, properties, and phenomena for the evaluation of performance of cementitious barriers



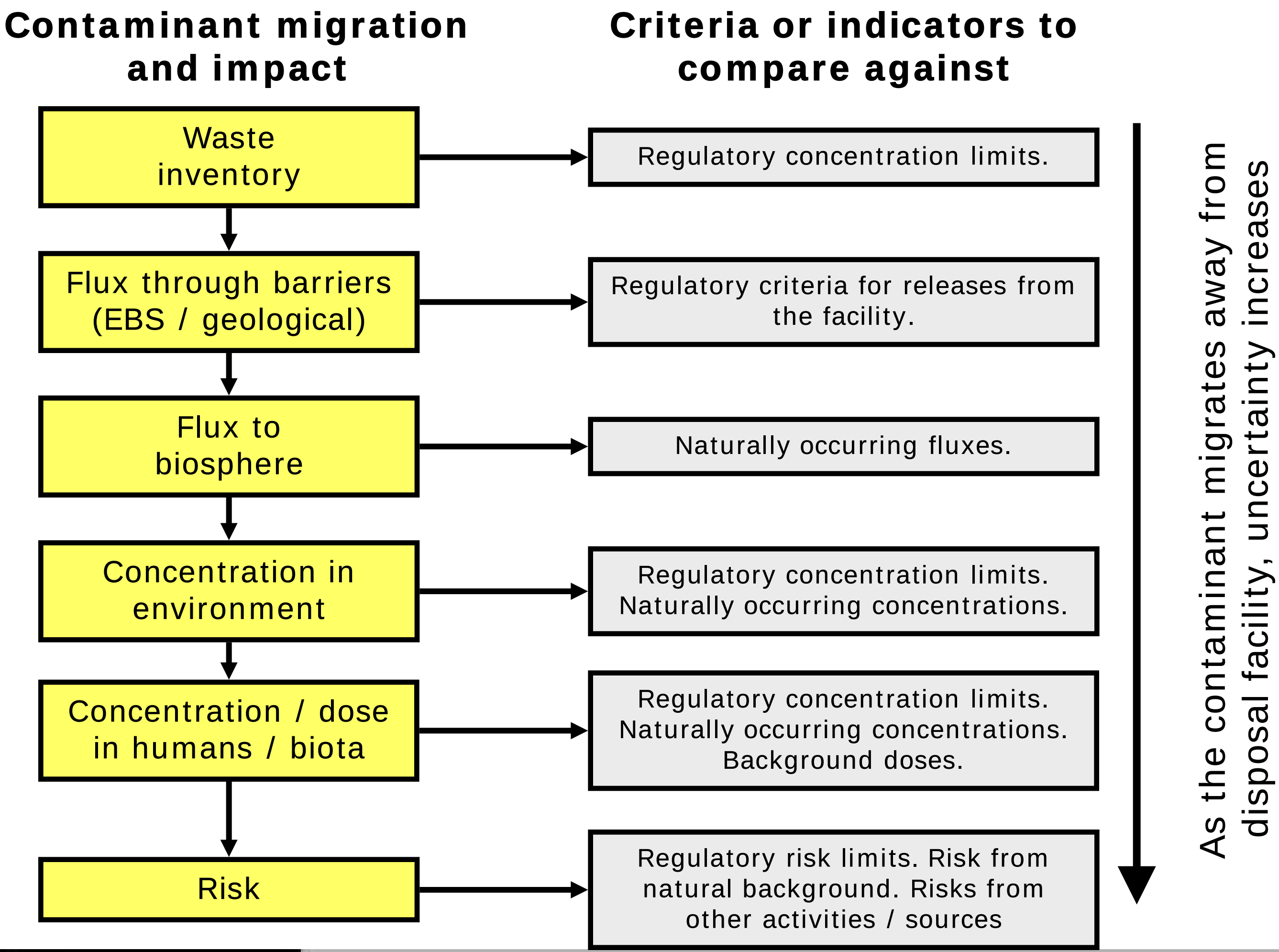
Modelling challenge

- Requirement to capture key FEPs for a complex system and its evolution for very long timescales
- PA models need to be
  - Flexible (analysis of a large number of scenarios, calculation cases in support of decision making and regulatory requirements)
  - Robust and transparent (Public confidence, by Regulator scrutiny)
  - As simple as possible, but to produce realistic results (competing requirements of complexity versus transparency)
- Underpinned by multiple models (see for example 2010 PCSA by NDA), BUT: how interfaced?
- Continuum of approaches for interfacing
  - Incorporate understanding only (as part of PA conceptual model)
  - Partial integration of computer models
  - Fully integrated

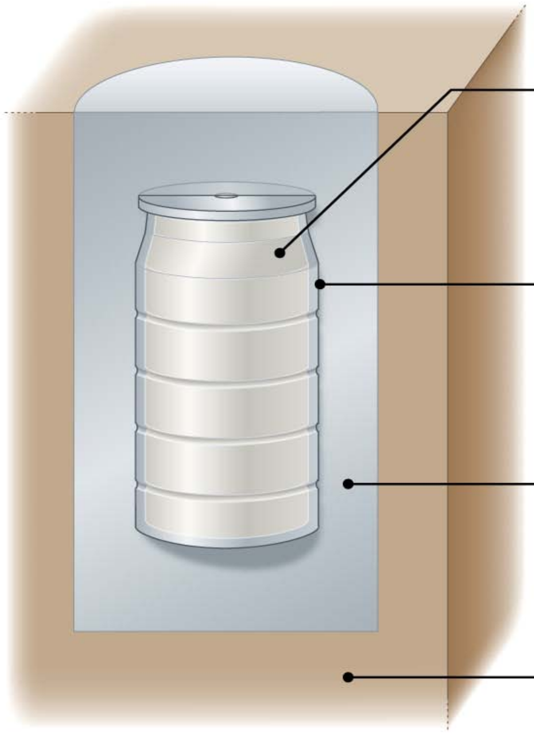
Trends in modelling approaches

- Integration with underpinning models via appropriate model platform
  - eg CBP, ASCEM
- Increasing use of probabilistic methods
  - (but makes for more complex analysis)
- Predominance of GoldSim software
  - (originally developed for Yucca mountain project)
- Increasing emphasis on model QA

Analysis of results



Barriers to radionuclide migration



Grouted Wasteform

- Slow radionuclide leaching rate
- Waste encapsulation and radionuclide sorption
- Low corrosion rate of metallic waste components
- Low permeability
- pH conditioning (low radionuclide solubility in pore water)

Stainless Steel Container

- Mechanical integrity
- Radionuclide uptake in/on corrosion products
- Redox buffer
- Vented to allow gas release

Cement Backfill

- Mechanical integrity
- Slow radionuclide leaching rate
- Low corrosion rate of stainless steel container
- pH/redox buffer (low radionuclide solubility in pore water)
- Radionuclide sorption

Lower Strength Host Rock

- Very low to low permeability
- Very high radionuclide retardation properties (high sorption capacity/colloid filter)
- Transport diffusive limited (slow)
- Medium to high self-sealing capability

0911-01-Nagra/NDA

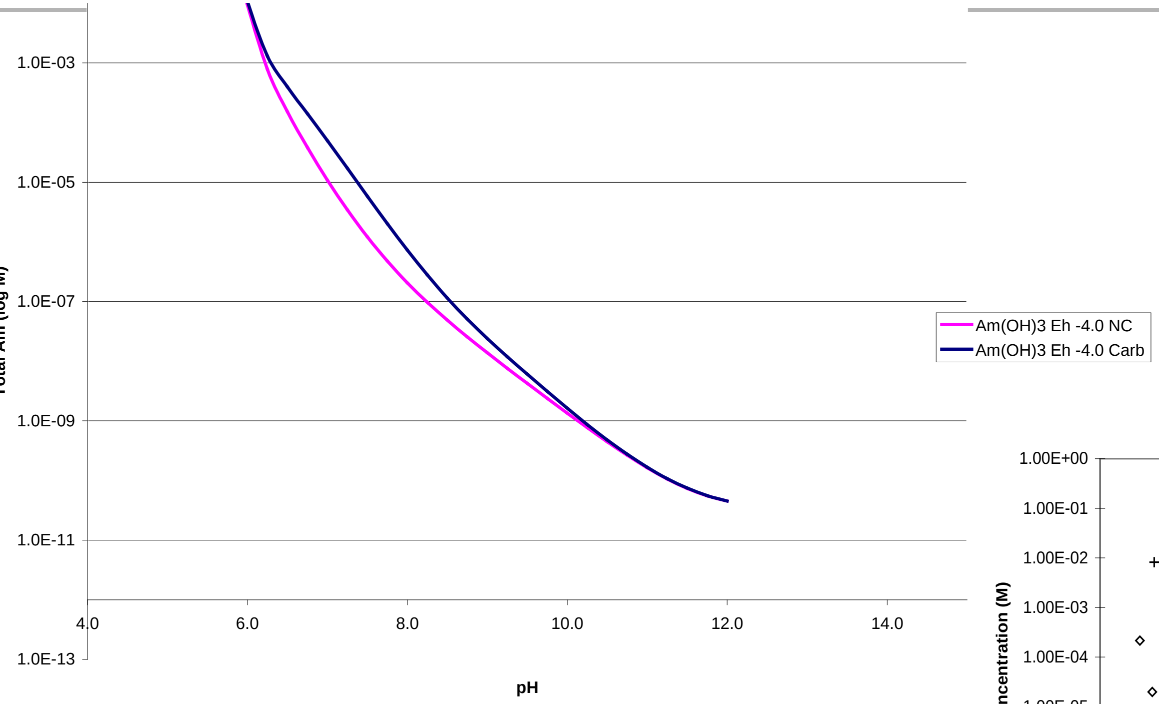
Factors influencing mobility

- **pH**
  - influences speciation (hydrolysis)
  - solubility generally decreases at higher pH (dependent on other ligands)
  - sorption generally increases at higher pH (dependent on other ligands)
- **Eh (pe)**
  - influences speciation (redox state)
  - mobility generally increases at higher Eh (pe)
    - some exceptions
    - also effects mineral surfaces
- **Substrate properties**
  - loading capacity
  - irreversibility
- **Complexation / colloids**
  - inorganic (CO_3^{2-}, OH-, F-. SO_4^{2-}, PO_4^{3-} etc)
  - organic (short chain aliphatics, humic/fulvic, anthropogenic complexing agents, degradation products etc.)
  - complexation generally increases mobility
- **Time**
  - increasing crystallinity
  - migration to less accessible sorption sites
  - radioactive decay

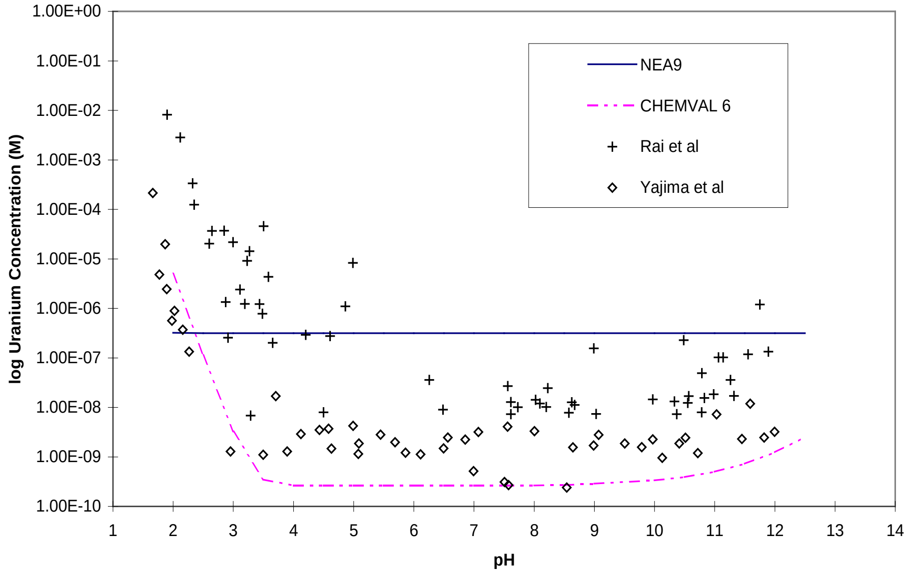
Processes influencing radionuclide migration

- The same processes often occur at the different scales in a GDF – wasteform, EBS, Geosphere and Biosphere
- **Processes affecting radionuclide release from the wasteform**:
  - wasteform dissolution or leaching
  - solubility limitation
- **Processes affecting radionuclide transport**:
  - advection and hydrodynamic dispersion
  - diffusion
  - transport by colloids, non aqueous phase liquids (NAPLs) and microbes
- **Processes affecting radionuclide retardation and immobilisation**:
  - sorption
  - complexation
  - precipitation/co-precipitation
  - molecular filtration and ion exclusion
  - rock-matrix diffusion
  - microbial activity
  - non-aqueous phase liquids

Solubility



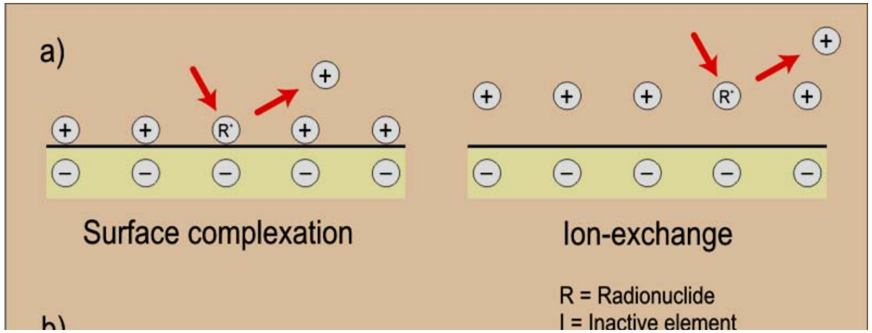
1.0E-03
1.0E-05
1.0E-07
1.0E-09
1.0E-11
1.0E-13
4.0
6.0
8.0
10.0
12.0
14.0
pH
Am(OH)3 Eh -4.0 NC
Am(OH)3 Eh -4.0 Carb

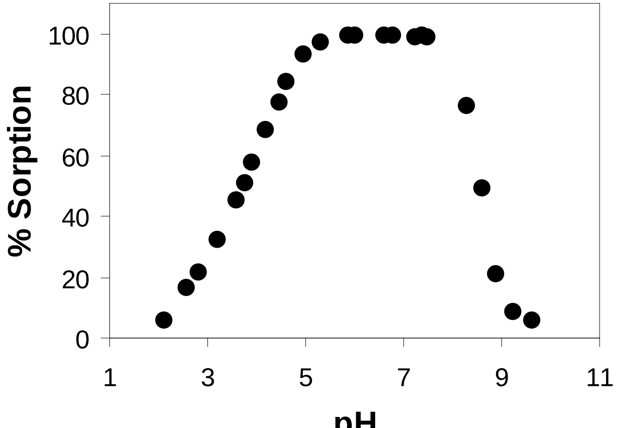


1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
log Uranium Concentration (M)
1 2 3 4 5 6 7 8 9 10 11 12 13 14
pH
NEA9
CHEMVAL 6
Rai et al
Yajima et al

Sorption

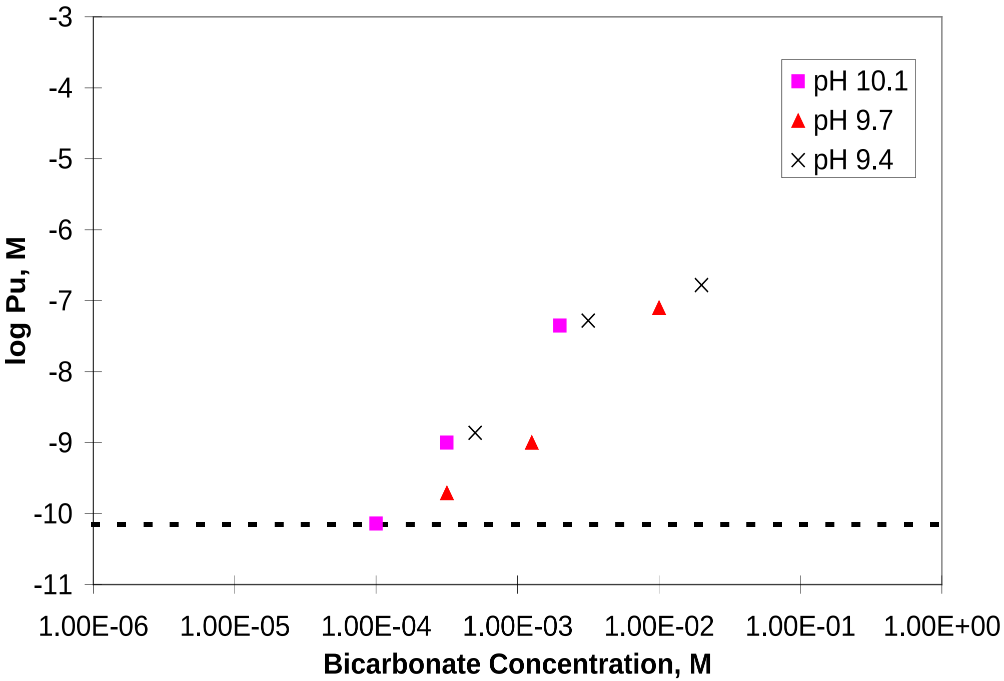
- Sorption is a set of processes, excluding the formation of discrete solid phases, by which entities such as ions or molecules are partitioned between the solution and a solid surface
- Sorption **may occur on any material surface exposed to water**. In the context of radionuclides disposed in a GDF, this includes
  - the wasteform and waste container (including corrosion products and secondary minerals formed from interaction with water),
  - the near field (which, dependent on the concept, contains clay-, salt- or cement-based backfills and buffers)
  - natural rock surfaces in the surrounding geosphere





U(VI) sorption onto Koongara weathered schist

Complexation



Yamaguchi, T., Sakomoto, Y. and Ohnuki, T.
Effect of the Complexation on Solubility of Pu(IV) in aqueous Carbonate Systems.
Radiochimica Acta **66/67** p9 (1994)

- General trend for actinides
  - OH^-, CO_3^{2-} > F^-, HPO_4^{2-}, SO_4^{2-} > Cl^-, NO_3^-
- Other elements (e.g. Cu, Zn, Cd, Pb etc) strongly associated with soft bases such as sulphides.
- Trend for actinides with organics
  - DTPA > EDTA > NTA > tricarboxylic acid > dicarboxylioc acid, monocarboxylic acid

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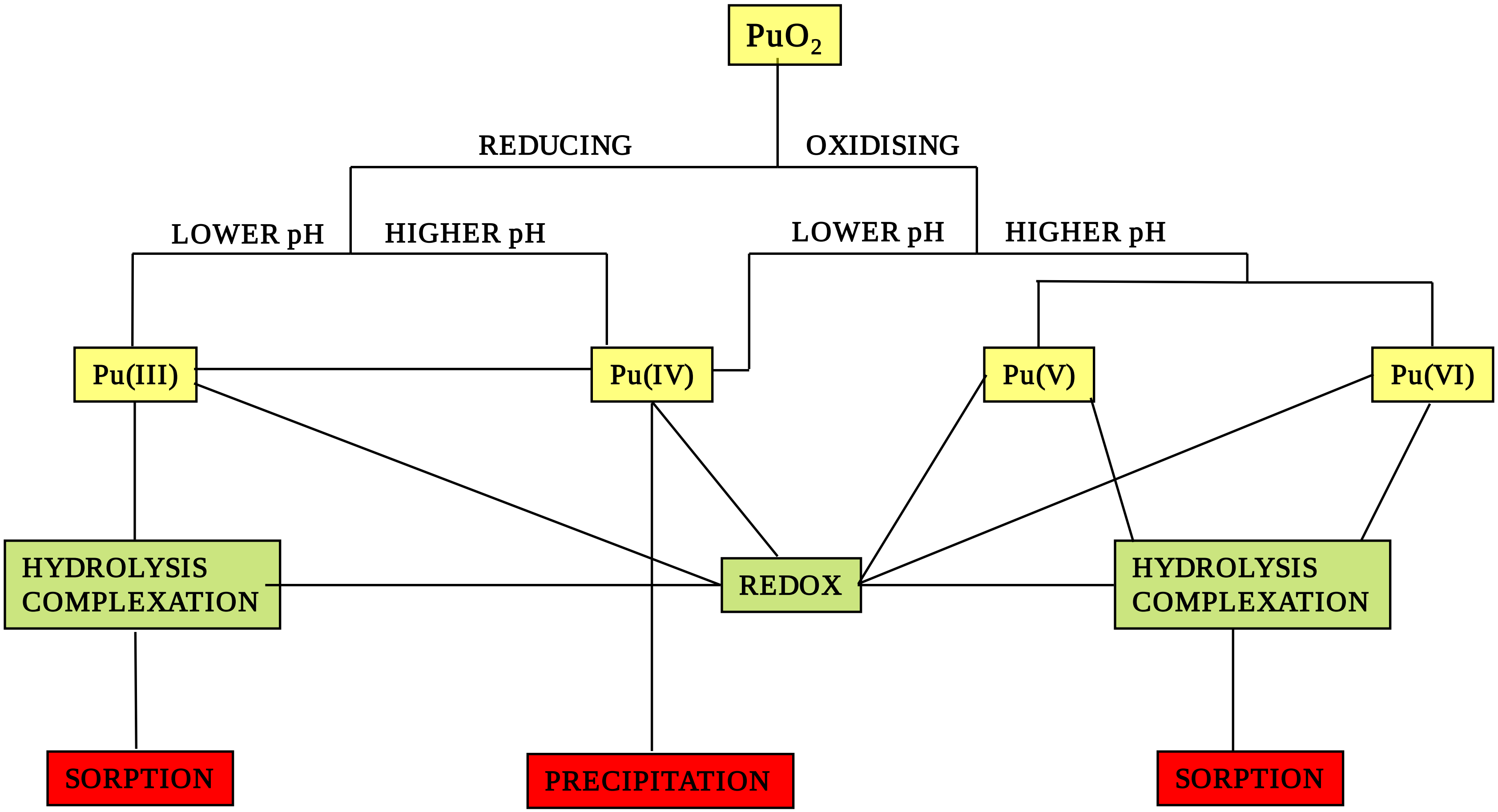

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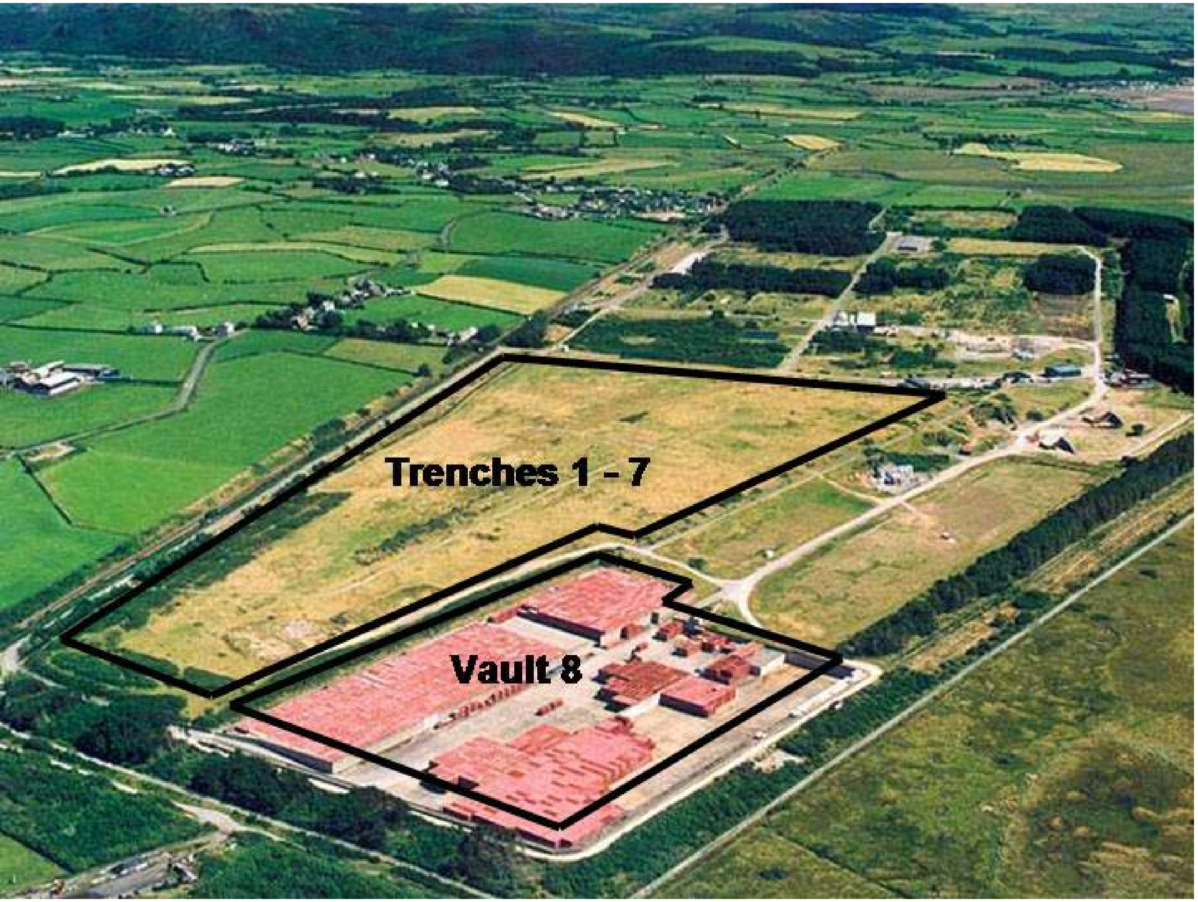
Representation within a PA

- The parameters used to describe radionuclide behaviour are:
  - the half-life of each radionuclide;
  - the rate at which each radionuclide enters the groundwater system;
  - the solubility limit of the radionuclide under the chemical conditions of the engineered system;
  - the sorption of each radionuclide onto the various engineered and natural barrier materials through which it may travel;
  - the accessibility of radionuclides to the pore space of certain engineered barrier materials and of different rock types.

Example outputs

Low level waste repository



Uranium solubility

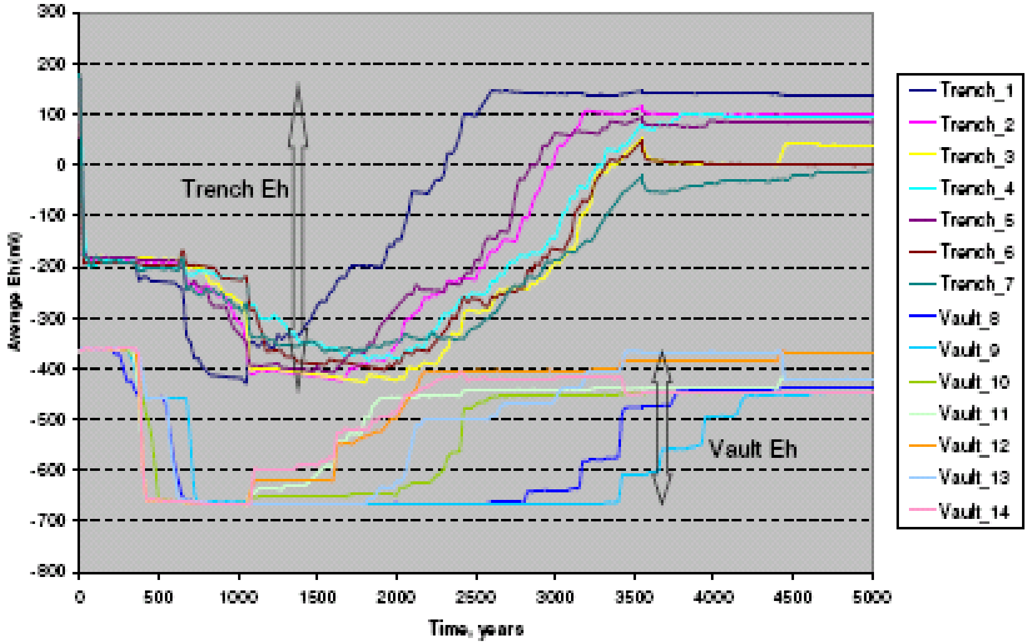
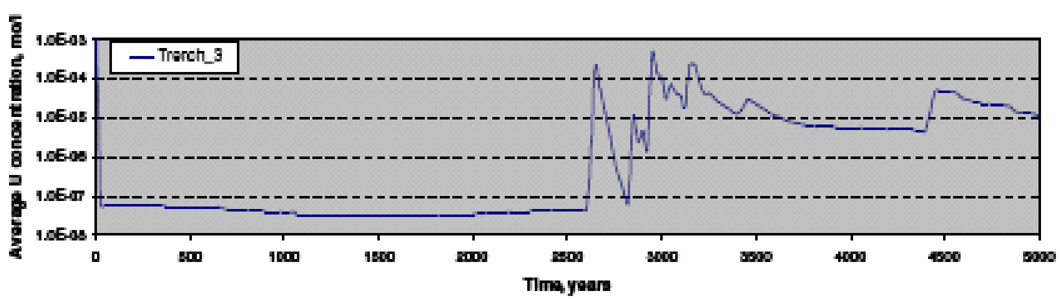


Figure 6.6 Evolution of Eh in the trenches and vaults (averaged values)



C-14 distribution

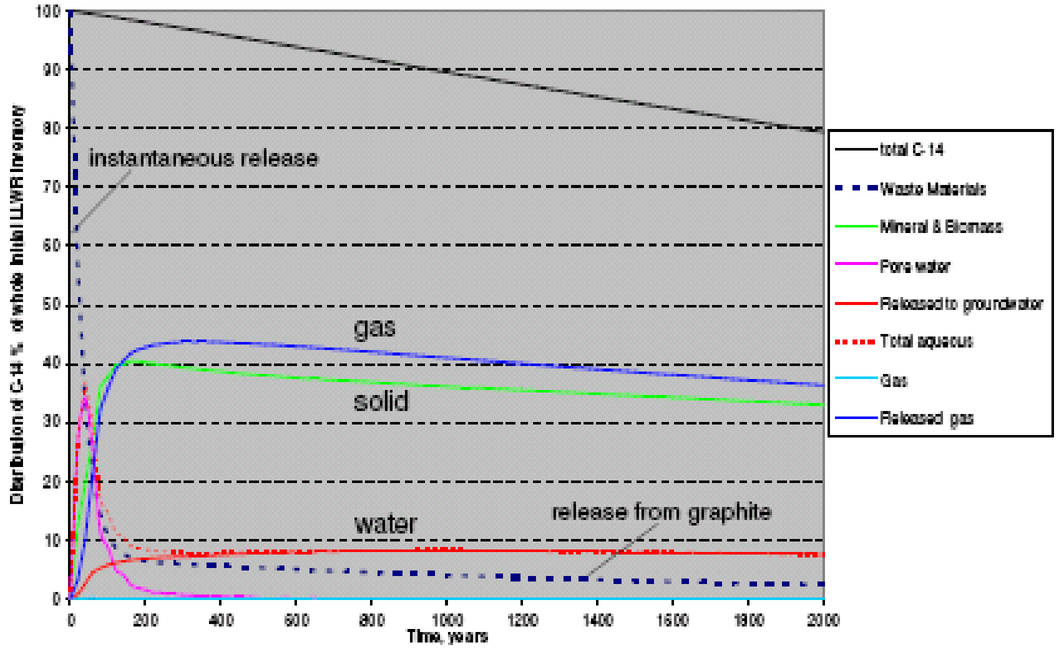


Figure 6.18 Summary of the partitioning of the C-14 inventory amongst solid, aqueous and gas phases, for the Case 2 groundwater flow model

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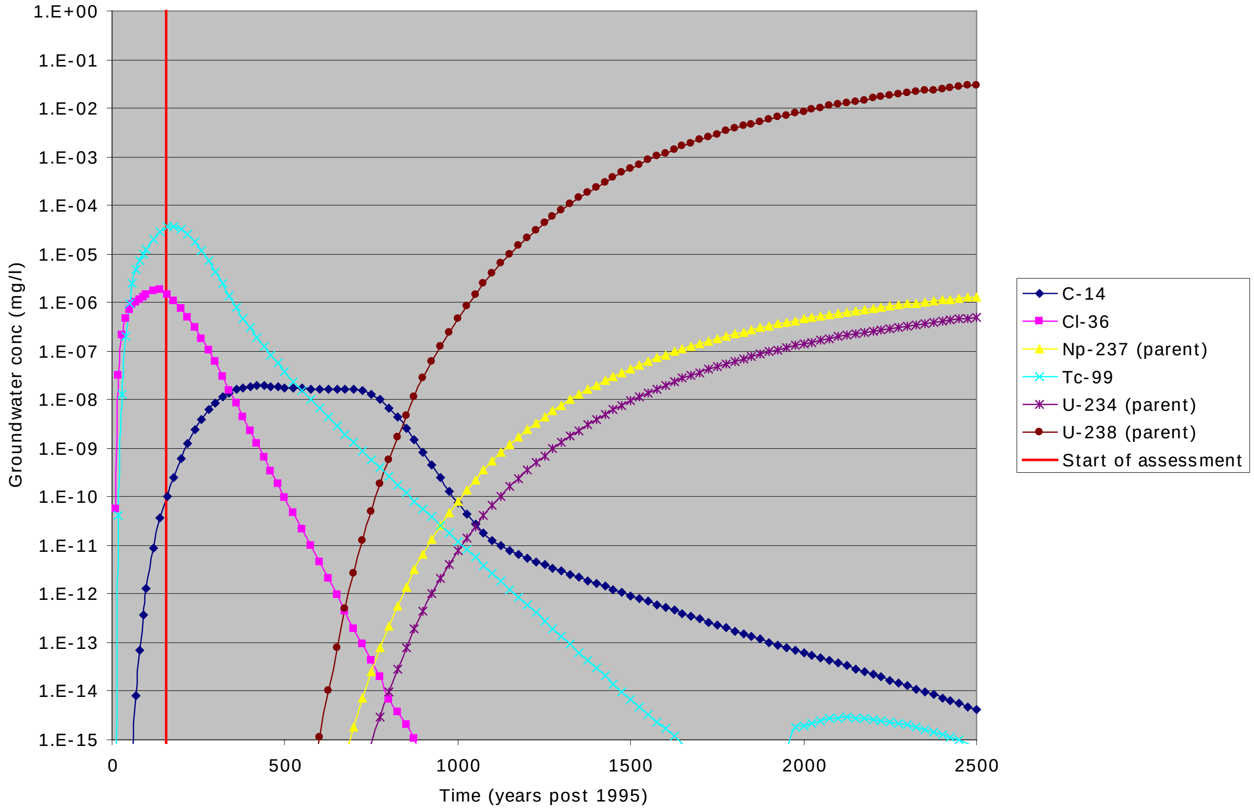
Solubility and sorption



Near-surface disposal, no containment-Concentrations of radionuclides at the site boundary over time

- Cl-36 and Tc-99 quickly washed out the near field
- C-14 solubility limited in near-field, slightly delaying release
- Uranium and neptunium significantly retarded in the near-field (and geosphere). Concentrations still increasing at assumed site termination

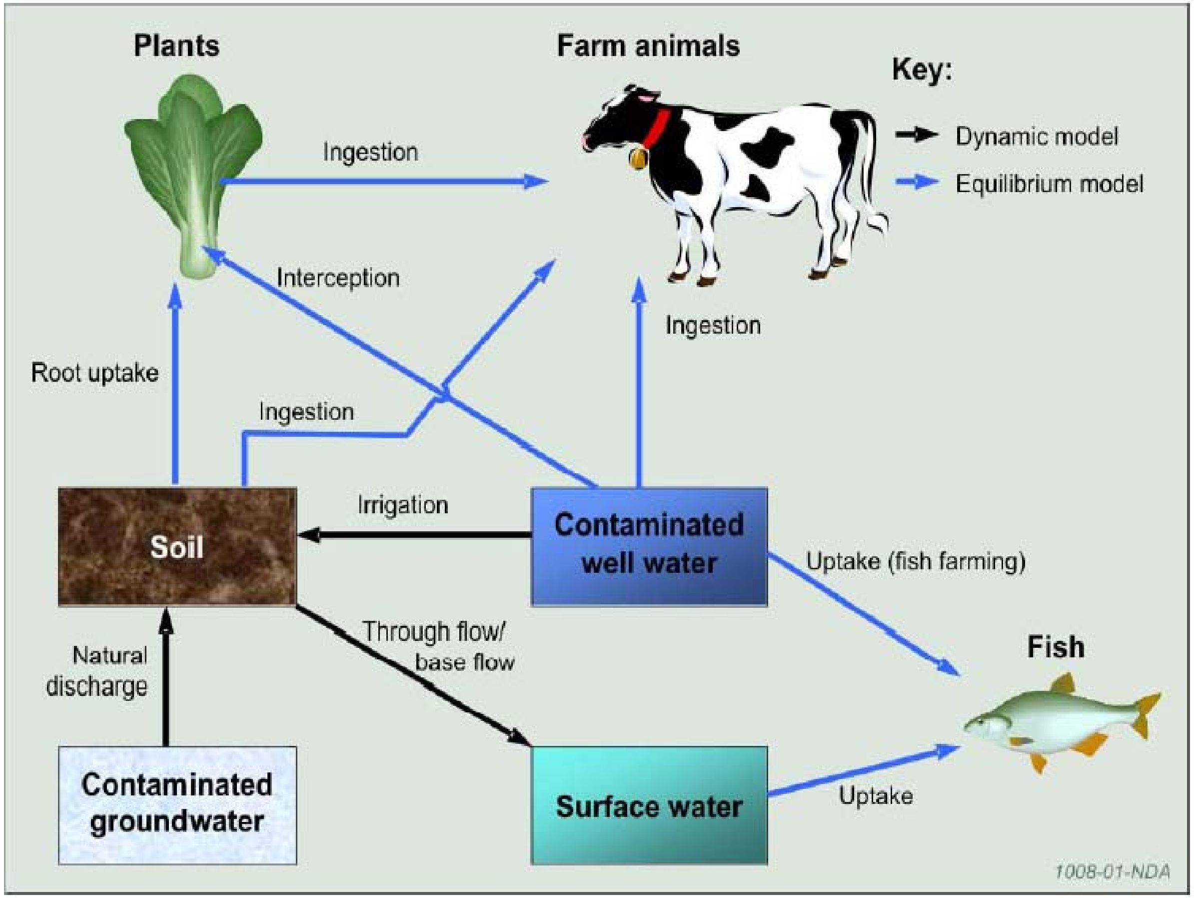
Dose and Risk – UK Context

- GRA - After the period of authorisation, the assessed radiological risk from a disposal facility to a person representative of those at greatest risk should be consistent with a risk guidance level of 10^{-6} per year (ie 1 in a million per year)
- Radiological risk corresponds to product of
  - Estimated effective dose
  - Estimated probability (quantified uncertainty) that dose received
  - Estimated probability that detriment occurs

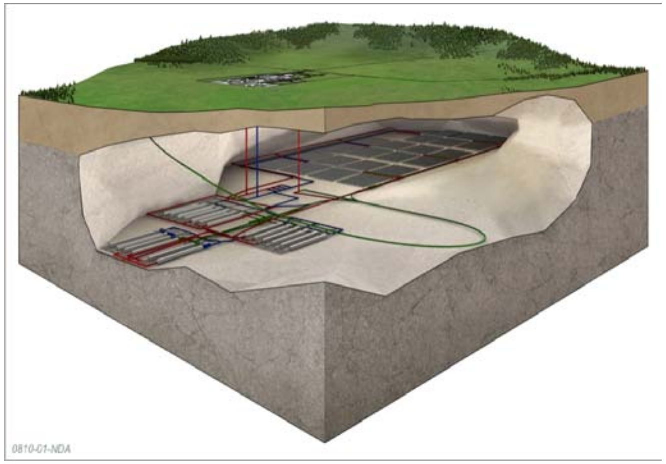
- Exposed group: For a given source, any group of people within which the exposure to radiation is reasonably homogeneous: where the exposure is not certain to occur, the term ‘potentially exposed group’ (PEG) is used.

- Choice of PEGs based on present and past habits

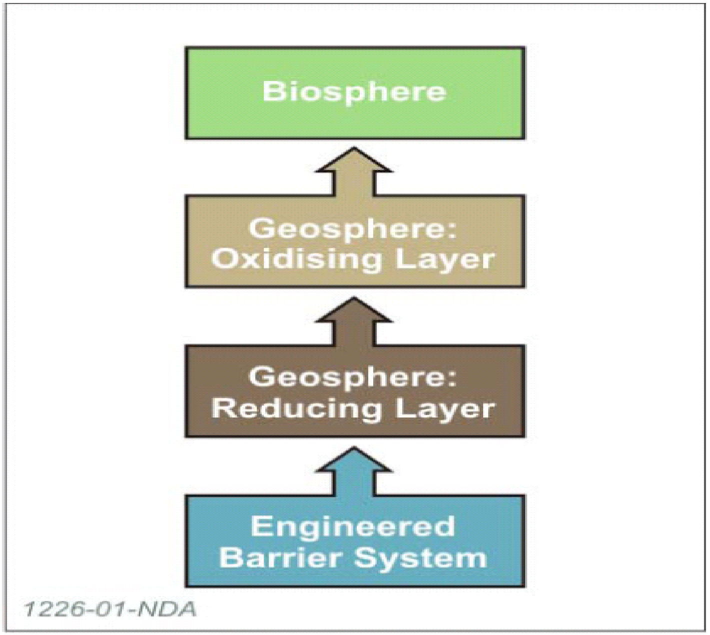
Radionuclides in the biosphere



UK Geological Disposal Facility



Schematic illustration of the conceptual model forming the basis of the PCSA calculations



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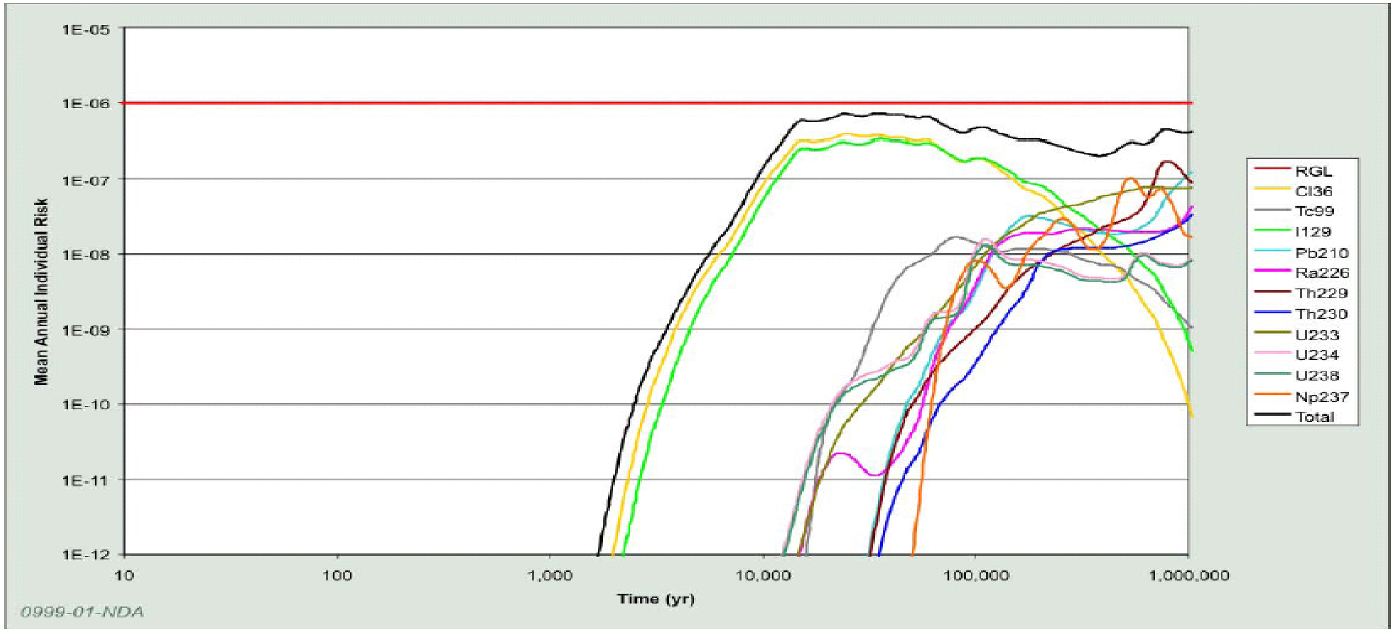
Risk Results from DSSC

Horizontal red line is the risk guidance level (RGL) from the GRA.



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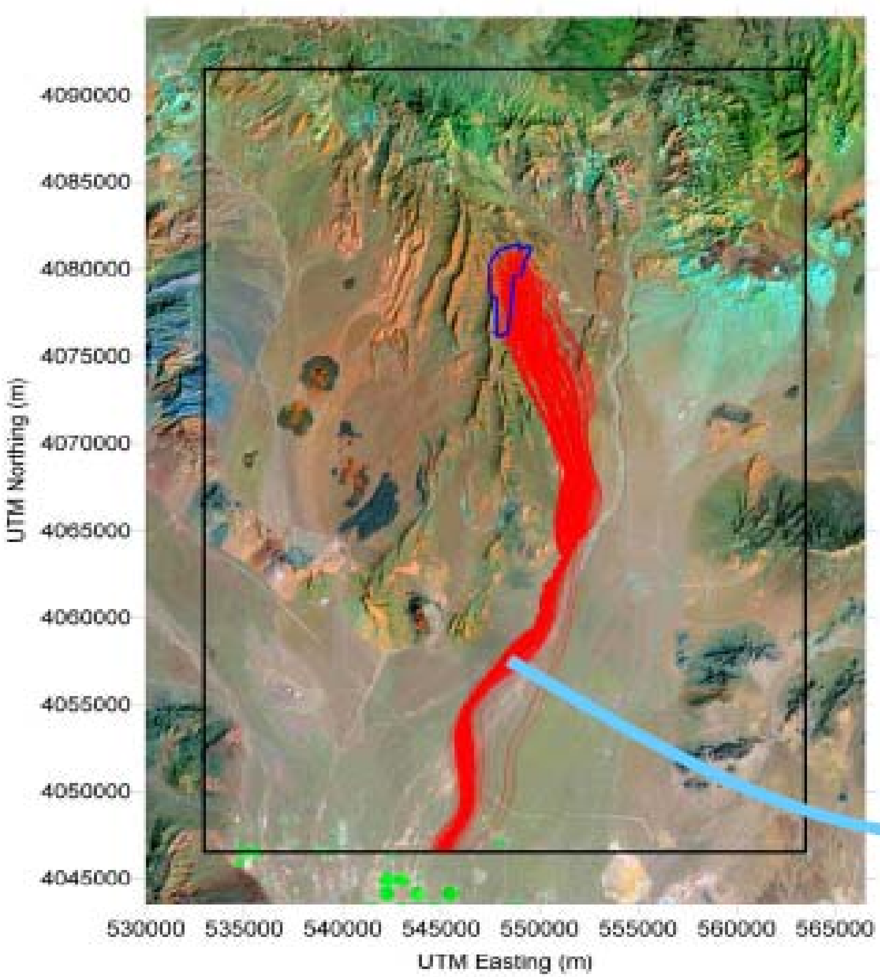
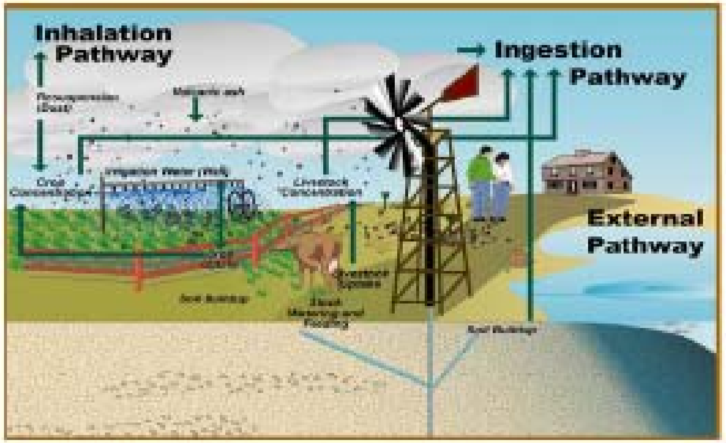
Yucca Mountain



Exposure pathways to Hypothetical Future Humans considered in TSPA for Yucca Mountain



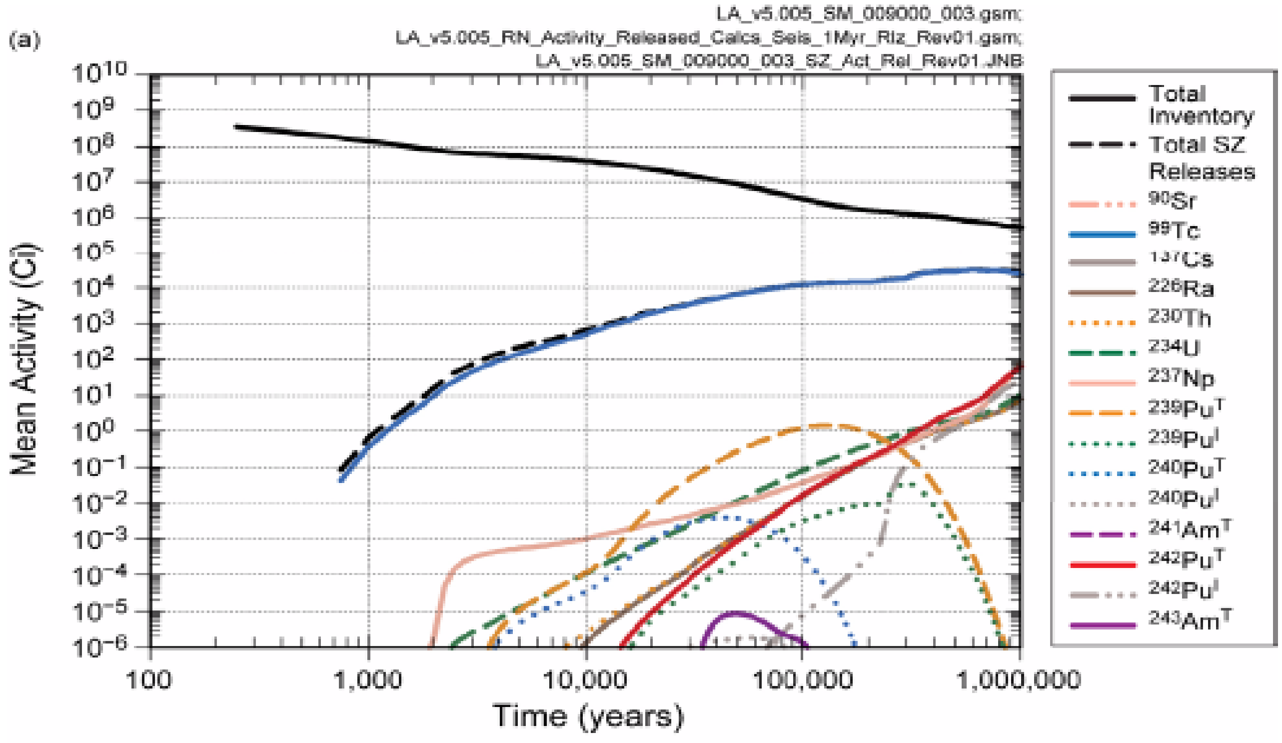
Modeled groundwater flow paths and hypothetical exposure pathways

Example results (Barrier capability analysis in the Yucca Mountain TSPA)

At I million yr, total mean activity released from SZ is about 5 % of total inventory

Short-lived species (e.g., Sr-90, Cs-137) are fully contained

Maximum releases of intermediate-lived species (e.g, Pu-239) are a small fraction of the total activity and occur before 1,000,000 yr



Mean Activity Released from the Saturated Zone Seismic Ground Motion Modeling Case Representative Subset of all Radionuclides

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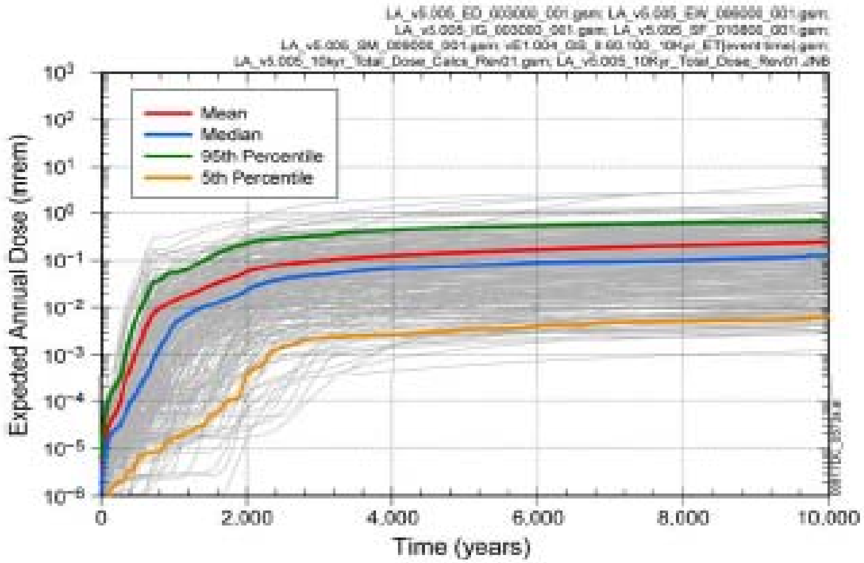
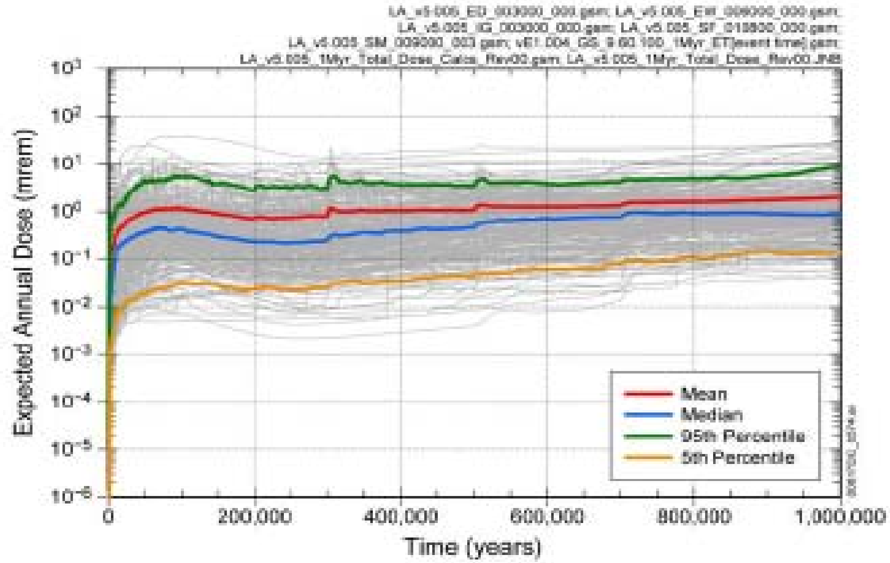
Example result: probabilistic dose results for Yucca Mountain TSPA

Total Mean Annual Dose



10,000 years



1,000,000 years

National Nuclear Laboratory

Conclusions

- Demonstration of the performance and safety of a disposal facility is made through a safety assessment and a safety case
- Aimed at synthesising system understanding, based on underpinning studies, involving the development and use of simplified models of reality (“total system model”)
  - these models are used as tools to analyse system performance in support of decision making / or demonstration of meeting regulatory requirements
- UK experience demonstrated by the 2011 LLWR ESC and NDA DSSC

References and background reading (2)

- IAEA, 2004. Safety Assessment Methodologies for Near Surface Disposal Facilities. Vienna.
- Environment Agency et al. Geological Disposal Facilities on Land for Solid Radioactive Wastes. Guidance on Requirements for Authorisation. (2009)
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- NDA. Geological Disposal: Geological Disposal, Generic Post-closure Safety Assessment, NDA/RWMD/030, December 2010.