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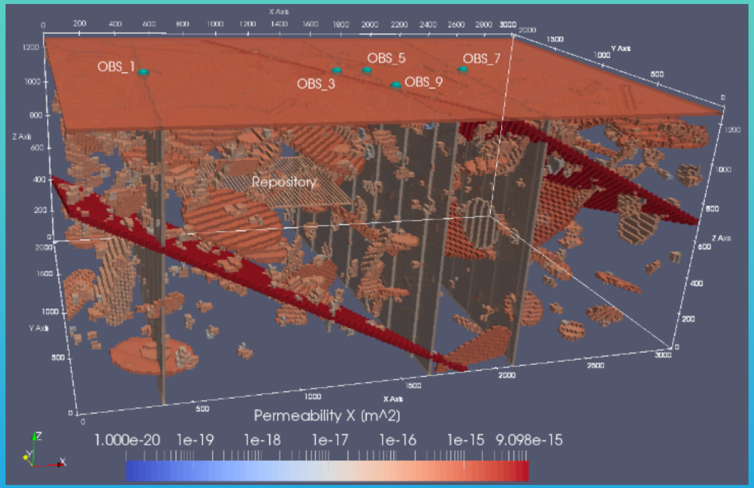

Use of Virtual Tracers in Repository Performance Assessment Modeling

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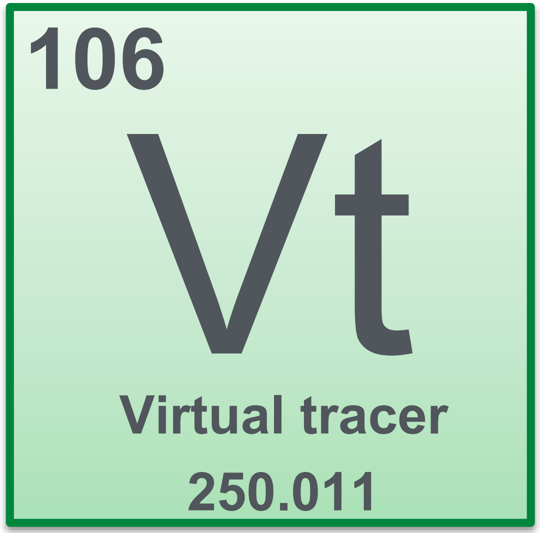
What is a virtual tracer?

- Computer simulated (not actual)
- Properties
  - Unrestricted
    - Conservative, reactive, solubility-limited, partitioning, decaying, specialized release mechanisms, etc.
- Purpose
  - To improve understanding of the model system
    - Bulk region characteristics affecting transport
    - Effects of release mechanisms on performance
    - Effects of engineered barrier system
    - Effects of natural barrier system
  - To precisely determine these characteristics and effects for each realization

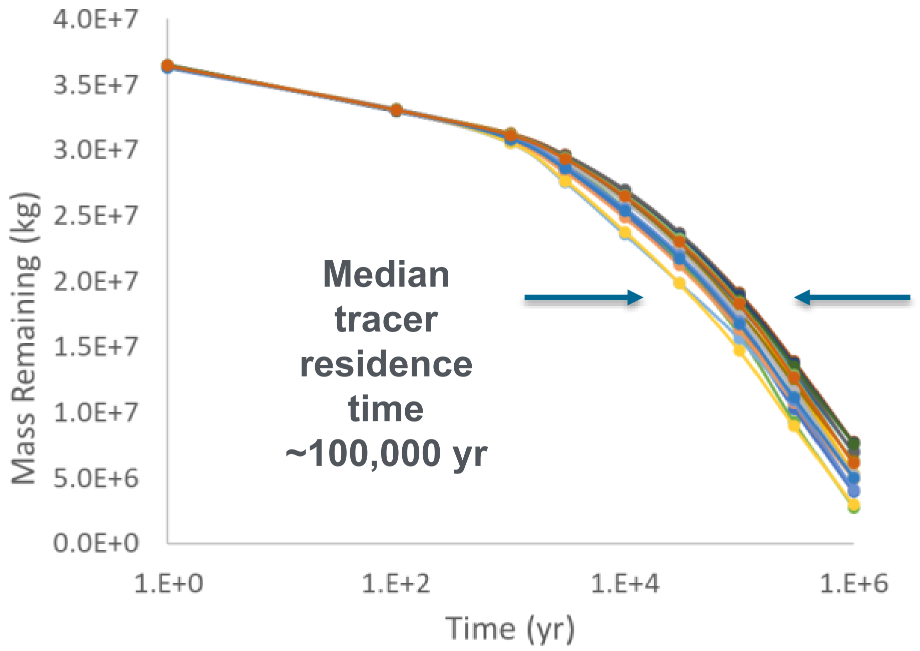


Virtual tracer measurements

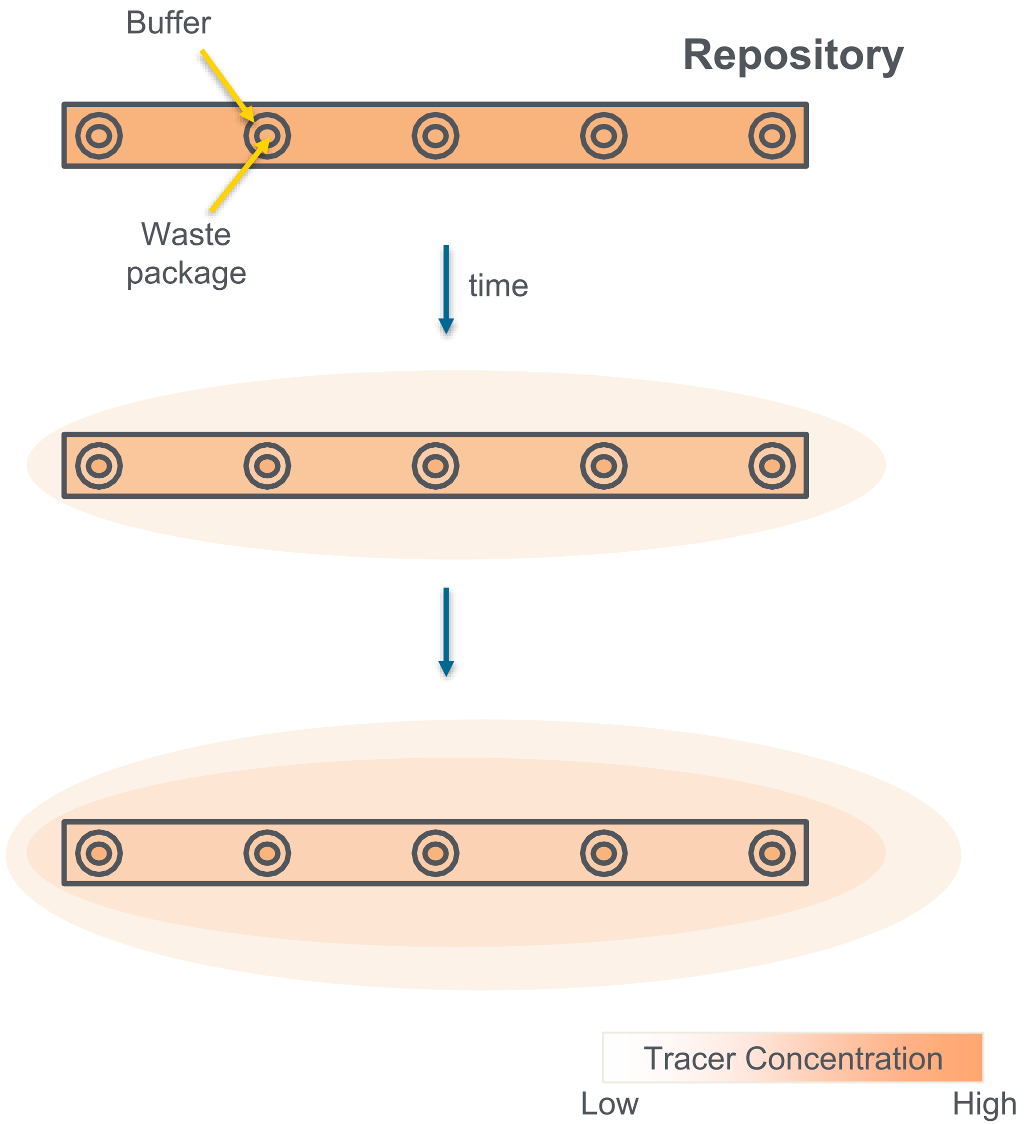
1. Hydrologic retention in the repository
2. Mean travel time to a location
3. Relative contributions of radionuclide release mechanisms
4. Waste form performance
5. Dispersion between source and receptor

1. Hydrologic retention in the repository (1/2)

- How well does the repository region hydrologically retain a tracer in its pore space?
  - Spike all pore space in repository region with a conservative tracer at time zero

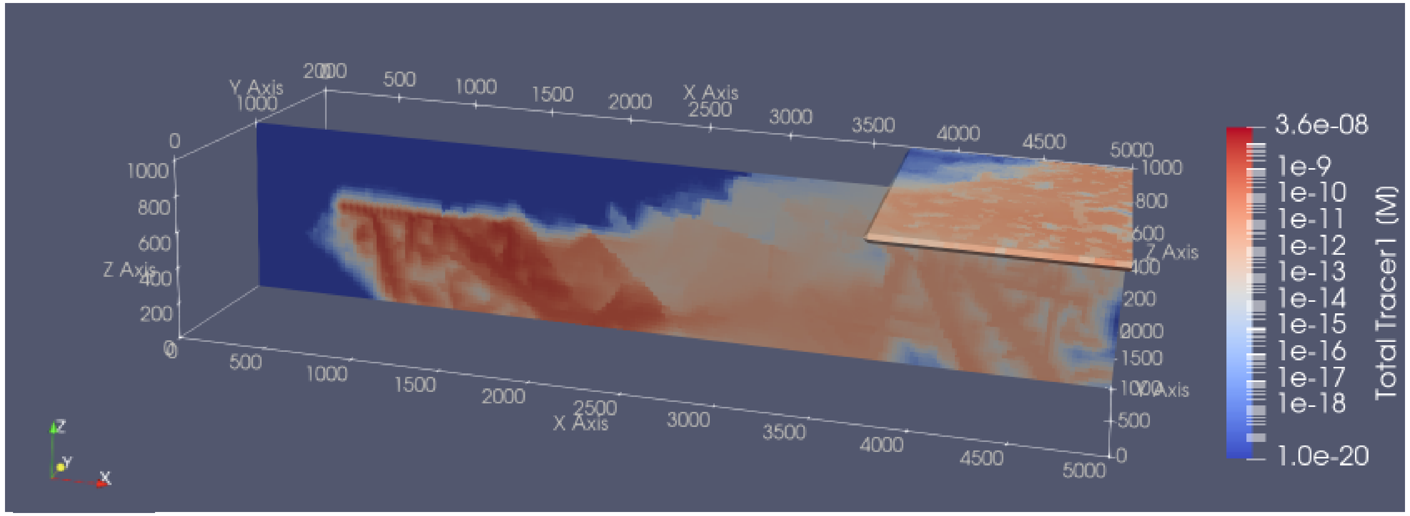


Tracer mass remaining in repository region for multiple realizations of a crystalline repository reference case

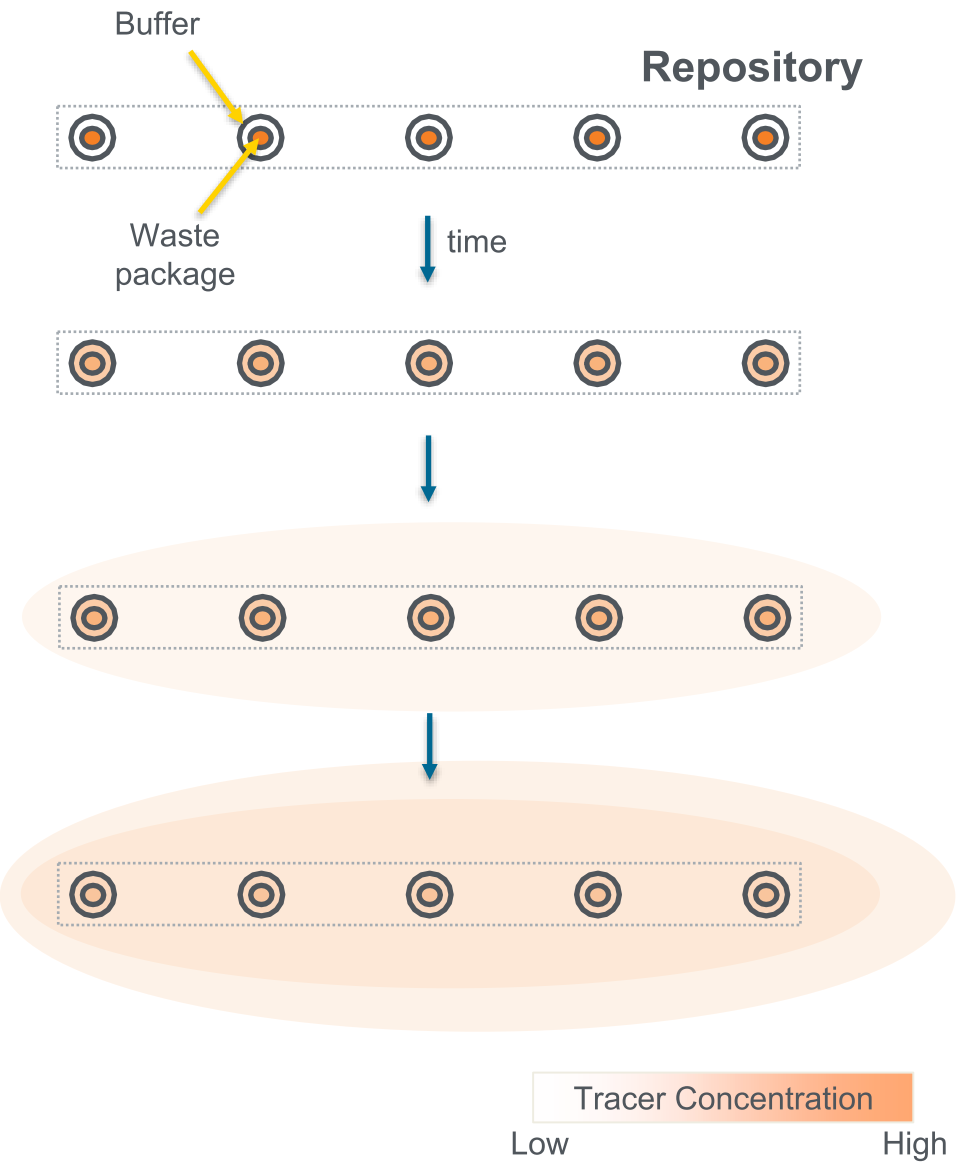


1. Hydrologic retention in the repository (2/2)

- Starting at the waste packages, how well does the repository region hydrologically retain a tracer?
  - Release conservative tracer at all waste package locations at time zero



Tracer plume for DECOVALEX-2023 Task F1 crystalline repository simulation at 100,000 years, Realization 1. **Median residence time** in the repository region measured to be approximately **1.79 × 10^6 years**.

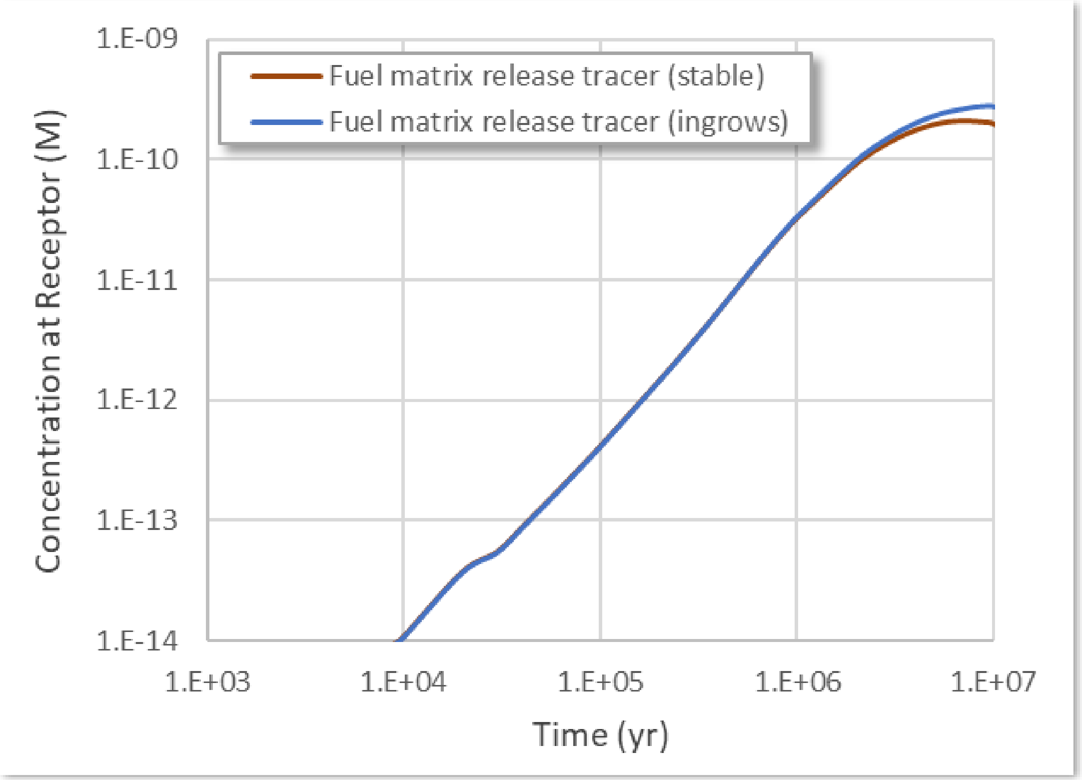


2. Mean travel time

- What is the mean travel time to the receptor?
  - Multiple sources released at different times
    - Different waste package failure times
    - Slow release from waste form matrix
  - Two conservative tracers
    - Same release concentrations
    - One decays or ingrows
  - Mean travel time (MTT) at receptor is

$$\mathrm{MTT} = \frac{-\ln\left({C_u}/{C_s} \right)}{r}$$

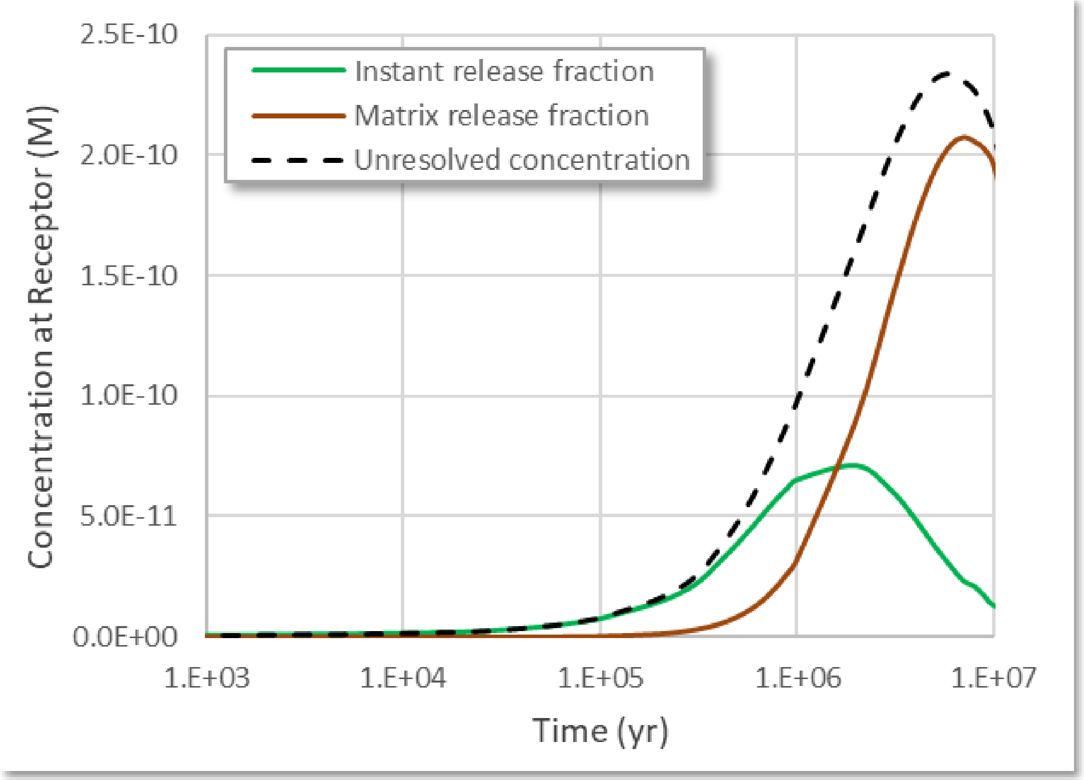
where C_s is concentration of stable tracer, C_u is concentration of decaying (or ingrowing) tracer, and r is the decay rate (Mariner et al. 2020, Section 3.2.6)



Fuel matrix tracers at receptor for DECOVALEX-2023 Task F1 crystalline repository simulation, Realization 1. **Mean travel time at 7 million years is 3.6 million years**.

3. Relative contributions of release mechanisms

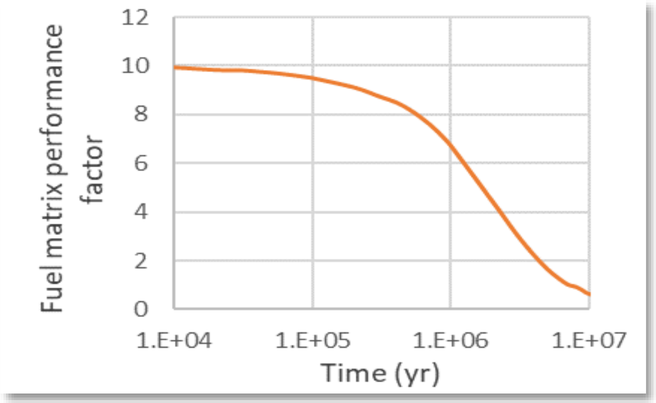
- What is the relative importance of different release mechanisms on concentrations at the receptor?
  - Not typically resolvable
  - Use separate tracers
  - In this example
    - 10% instant release fraction
    - 90% from fuel matrix degradation
    - Instant release dominates concentrations at receptor for the first 1 million years

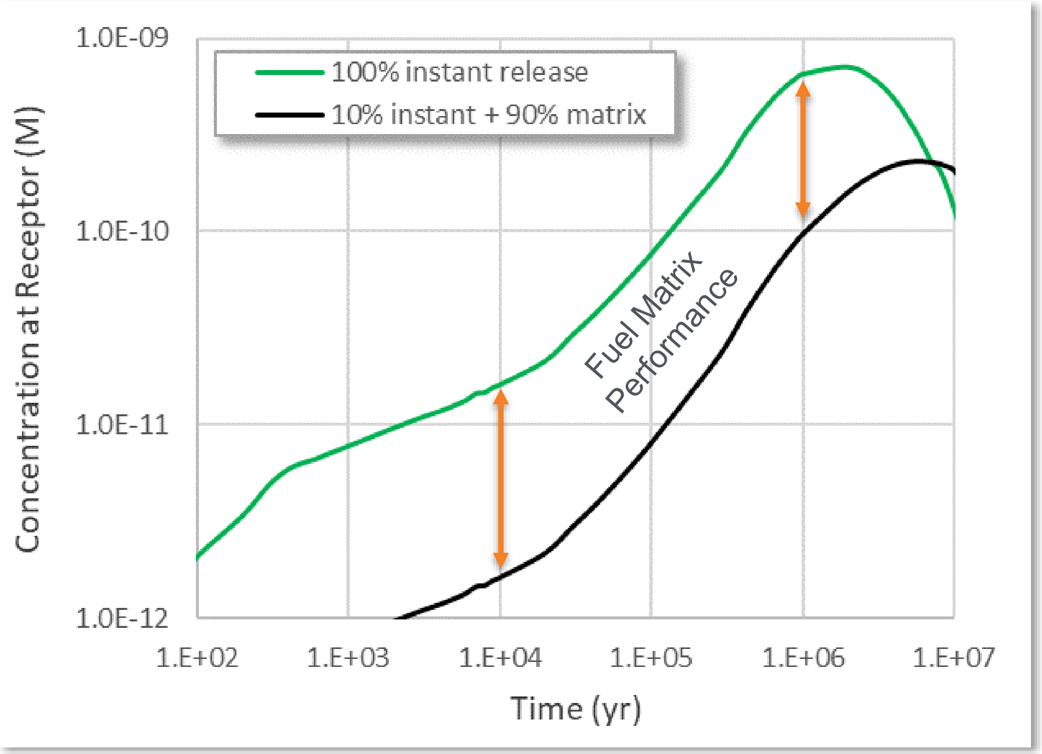


Instant release and matrix release fractions at receptor for DECOVALEX-2023 Task F1 crystalline repository simulation, Realization 1.

4. Waste form performance

- How much does waste form performance reduce concentrations at the receptor?
  - Use same instant release and matrix release tracers
    - Scale instant release breakthrough curve to calculate 100% instant release breakthrough
  - Waste form performance factor as a function of time

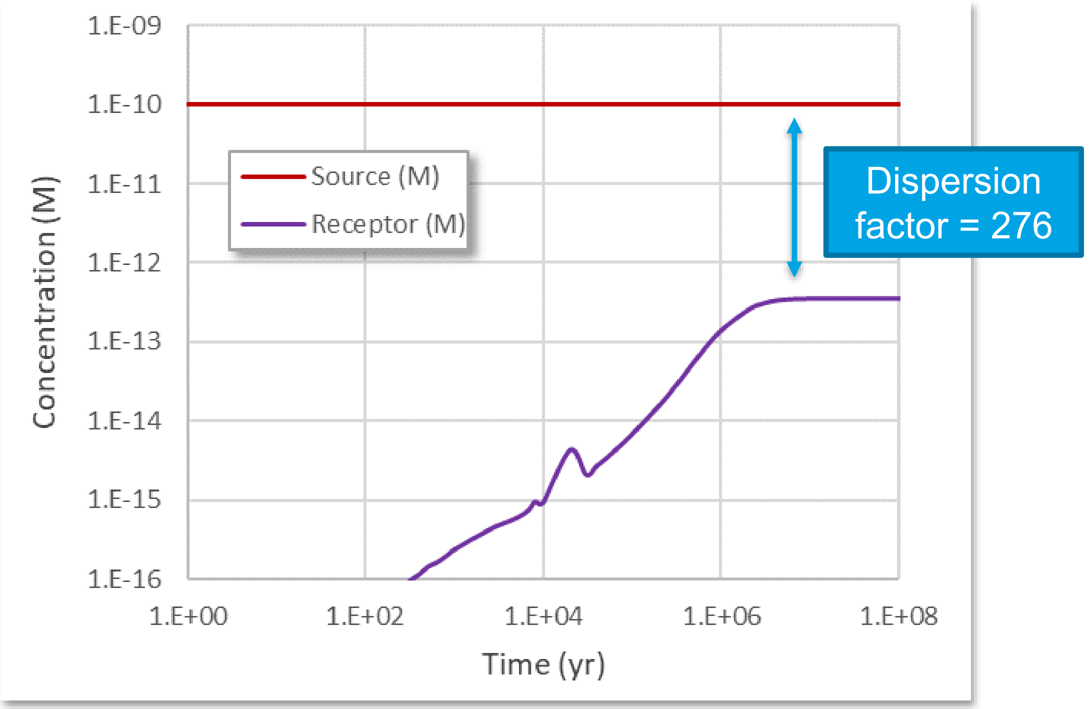




Fuel matrix performance for DECOVALEX-2023 Task F1 crystalline repository simulation, Realization 1. Calculated from fuel matrix and instant release tracers.

5. Dispersion

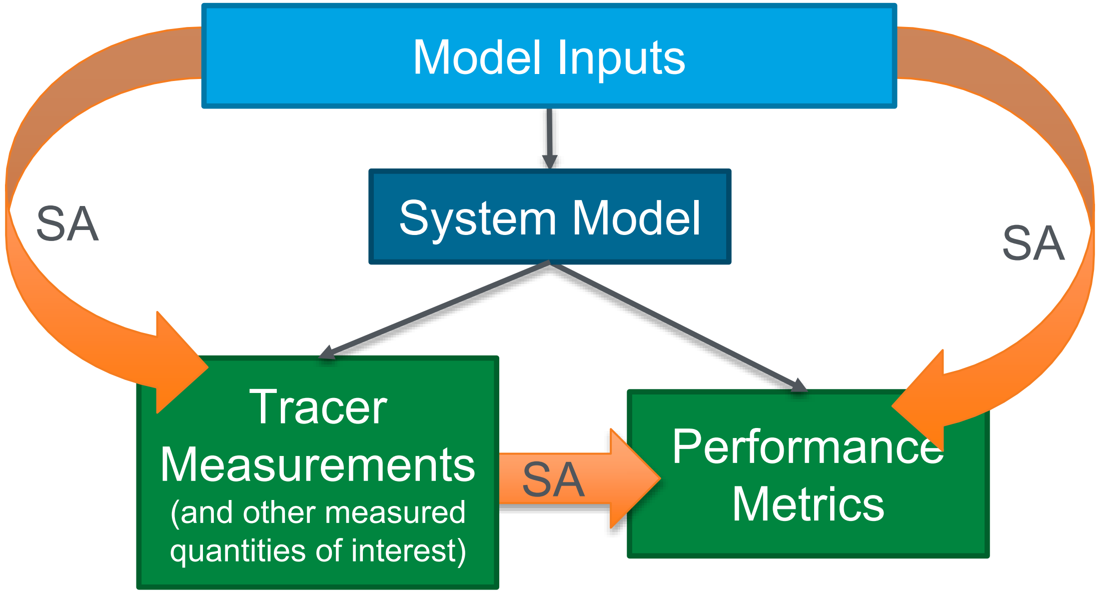
- How much does dispersion reduce radionuclide concentrations at the receptor?
  - Causes of dispersion
    - Branching and merging of flow (pore tortuosity, intersecting fractures, heterogeneous flow systems)
    - Molecular diffusion
    - Numerical error (estimated via convergence testing)
  - Measure dispersion
    - Maintain tracer concentration at the source
    - Run model to steady state
    - Compare receptor and source concentrations at steady state



Concentrations of tracer at the source and receptor for DECOVALEX-2023 Task F1 crystalline repository simulation, Realization 1.

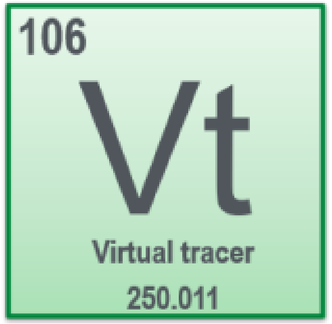
Use of tracer measurements in sensitivity analysis (SA)

- Tracer measurements provide
  - Subsystem characteristics, performance factors, source/mechanism contributions, etc.
- Sensitivity analysis (SA)
  - Considers uncertainty
  - Quantifies relationships between inputs and outputs (and outputs and outputs)
    - Model inputs
    - Tracer measurements (and other measured quantities of interest)
    - Performance metrics (e.g., peak mean concentration at receptor)
- Ultimate goal of performance assessment
  - Quantify, with uncertainty, the effects of inputs, processes, and subsystem characteristics on system performance



Conclusions

- Virtual tracers are versatile and powerful tools for directly measuring
  - System and subsystem properties
    - Hydrologic retention in the repository region
    - Contributions of different radionuclide release mechanisms
    - Mean travel times
  - Effects of subsystem processes and features on repository model performance
    - Waste form performance
    - Waste package performance
    - Dispersion
- Combined with sensitivity analysis, virtual tracers can be used to assess measured subsystem properties and their effects on performance with uncertainty



Future work

- Use a full set of virtual tracers in a probabilistic simulation
- Include the resulting tracer measurements in sensitivity analyses
- Use results to improve
  - Understanding of subsystem behavior
  - Assessment of the effects of subsystem processes on repository performance, with uncertainty

References

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