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U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Spent Fuel and Waste Science and Technology (SFWST)

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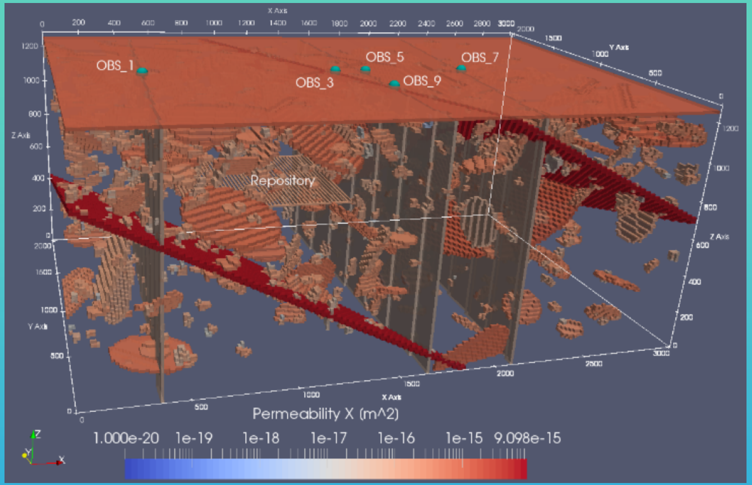

Assessing the Consequences of Postclosure Criticality in Spent Nuclear Fuel

SAND2022-XXXX PE

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To the extent discussions or recommendations in this presentation conflict with the provisions of the Standard Contract, the Standard Contract governs the obligations of the parties, and this presentation in no manner supersedes, overrides, or amends the Standard Contract.

This presentation reflects technical work which could support future decision making by DOE. No inferences should be drawn from this presentation regarding future actions by DOE, which are limited both by the terms of the Standard Contract and Congressional appropriations for the Department to fulfill its obligations under the Nuclear Waste Policy Act including licensing and construction of a spent nuclear fuel repository.

Background

- Disposal of spent nuclear fuel (SNF) is the responsibility of the US Department of Energy (DOE)
- Thousands of metrics tons of SNF has accumulated, much of which is stored in dual-purpose canisters (DPC)
- DPCs are licensed for storage and transportation but were not designed for disposal; not designed to preclude criticality over repository timescales (10^6 yrs)
- DOE has been investigating disposal of SNF in DPCs
  - Avoids expense and worker dose associated with repackaging
  - Introduces issues with respect to possible repository temperature limits
  - Introduces issues with respect to emplacement and engineering
  - Introduces possibility of postclosure criticality

Managing Potential Occurrence of Postclosure Criticality

- Lower the probability of occurrence of postclosure criticality so that it is unlikely from a regulatory point of view
  - Use long-lasting neutron absorbing material in future DPCs; would require new license
  - Revise the loading map for to-be-loaded SNF; would not require new license and is being explored as a possibility
  - Add filler material to already-loaded DPCs; subject of talks at this conference
- Assess the consequences of postclosure criticality and include in repository performance calculations or exclude on the basis of low consequence
  - Identify features, events, and processes (FEPs) that need to be considered
  - Develop the tools needed to include the relevant FEPs in models used to evaluate the performance of hypothetical repositories for 10^6 years (performance assessment)
  - Conduct performance assessment analyses both with and without the occurrence of postclosure criticality and compare the results

Analysis of FEPs

- Started with the list of FEPs developed for the Yucca Mountain Repository Performance Assessment
  - Identified FEPs that could affect potential for and/or extent of a criticality event
  - Identified FEPs that could be affected by a criticality event
  - Identified FEPs that fell into both categories
  - Identified FEPs not previously considered for further development
- Undisturbed repository conditions (examples)
  - Geometry and materials of waste package components
  - Degradation rates of various components
  - Backfill permeability
  - Depth and saturation status of repository
- Termination mechanisms: grid spacer degradation

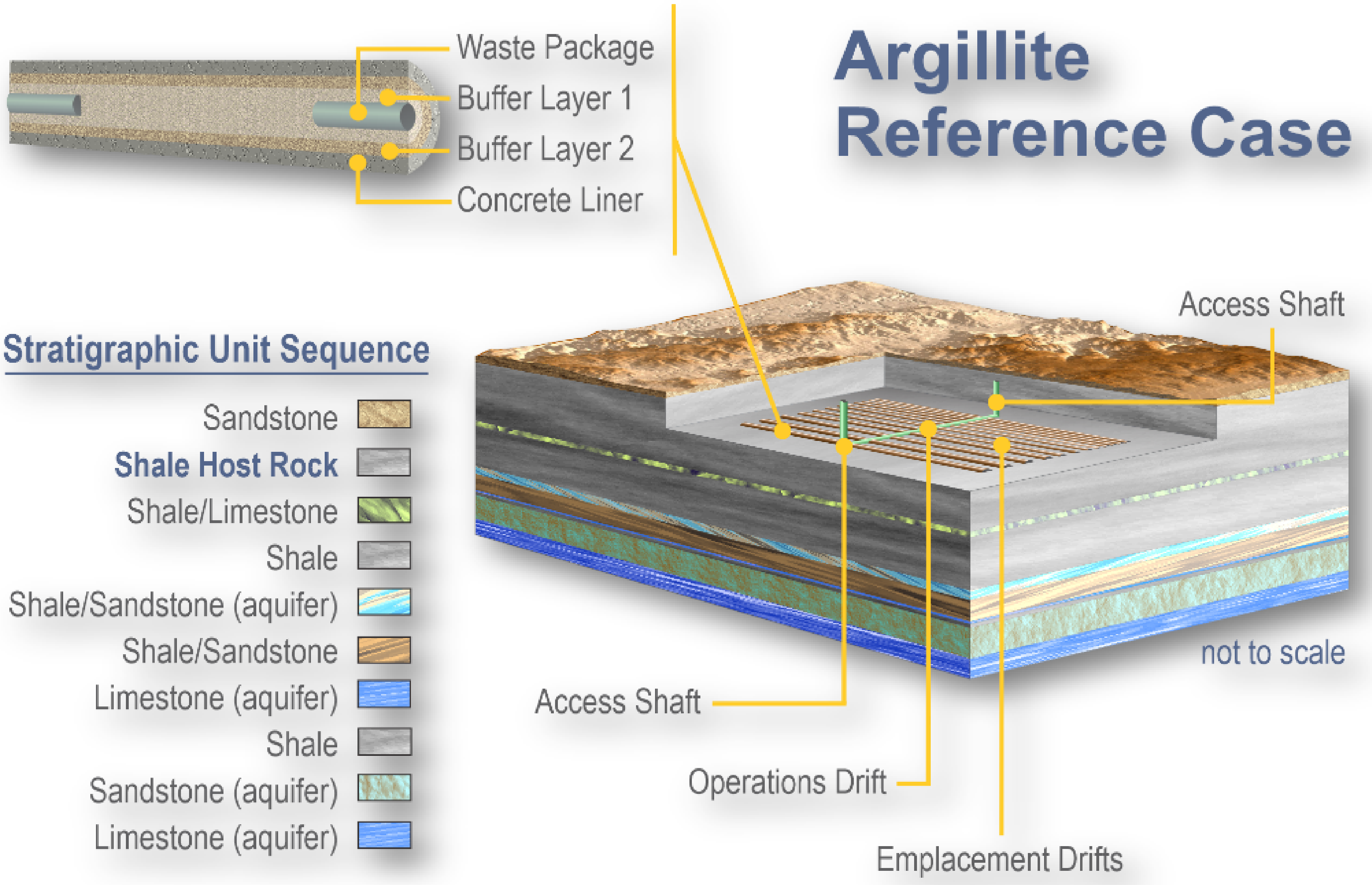
Analysis of FEPs (cont'd)

- Nuclear Criticality in a Waste Package
  - Waste package must fail first and allow water to enter
  - Evaluation of as-loaded conditions indicate that about 70% of DPCs would remain subcritical under two different stylized scenarios (loss of absorbers and loss of baskets)
  - Neutronics of the critical system inside the DPC are coupled with the thermal-hydrologic properties of the repository
- Thermal Effects (examples)
  - Change properties of materials both inside and outside the waste package, which would affect groundwater flow and radionuclide transport
  - Affect corrosion rates for grid spacers, baskets, cladding, fuel, etc.
- Inventory Effects
  - Generate fission products, some of which would not otherwise be included in performance assessment calculations
  - Generate and deplete fissile material
  - Generate and deplete neutron absorbers

Develop Tools to Model Relevant FEPs

- Used PFLOTRAN to model the performance of a hypothetical saturated repository in a shale host rock 500 m below the ground surface
- PFLOTRAN already includes many of FEPs associated with undisturbed repository conditions, but not criticality
- Developed a criticality submodule
  - Heat of criticality
  - Change in radionuclide inventory
  - Decay heat from fission products created during the criticality event
  - Specify start time and end time for criticality event
- Modify PFLOTRAN
  - Include saturation and temperature dependent anisotropic thermal conductivity
  - Include change in backfill materials (bentonite to illite)
- Implementation of a grid spacer degradation model currently in process

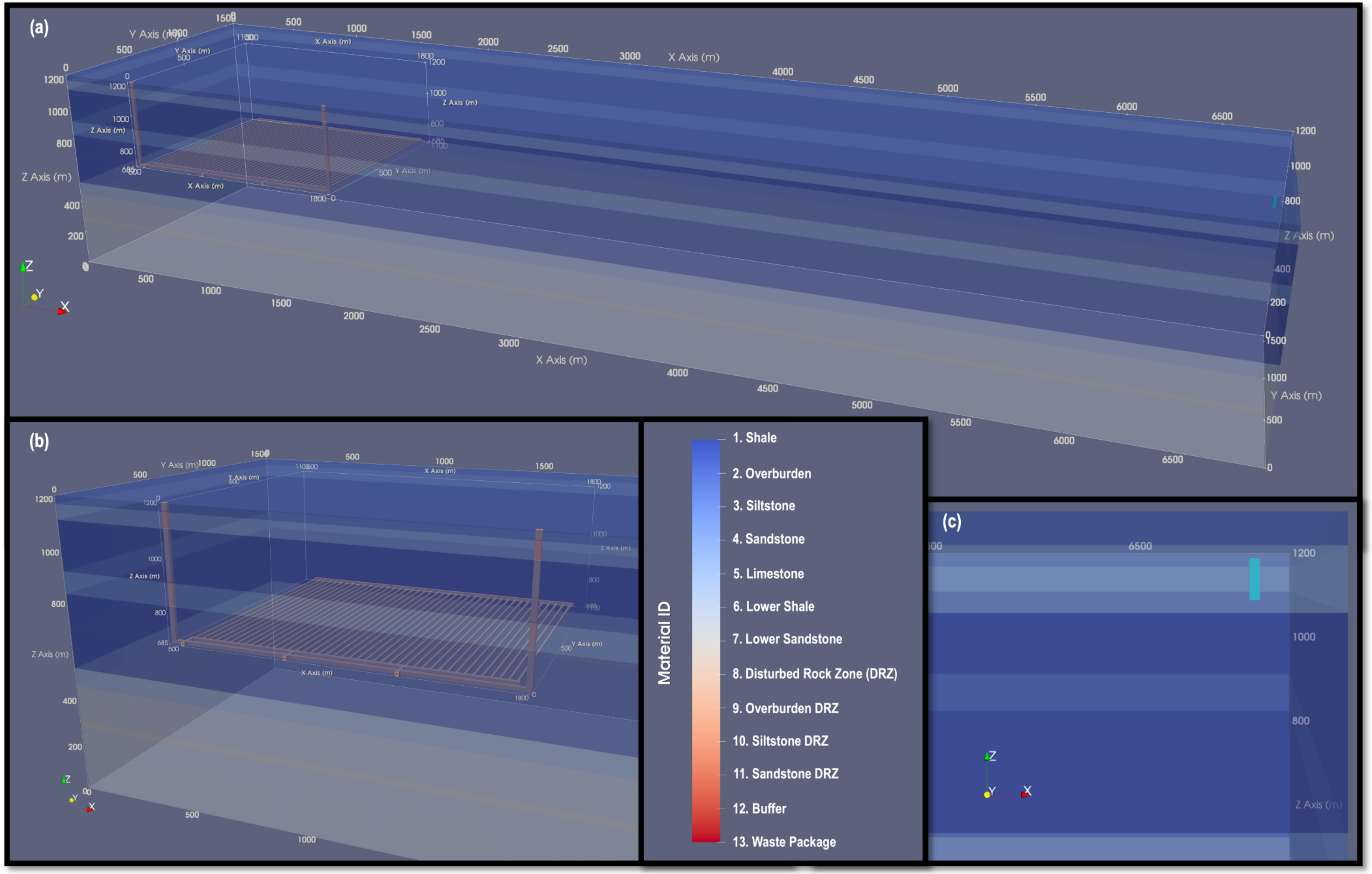
Hypothetical Saturated Repository



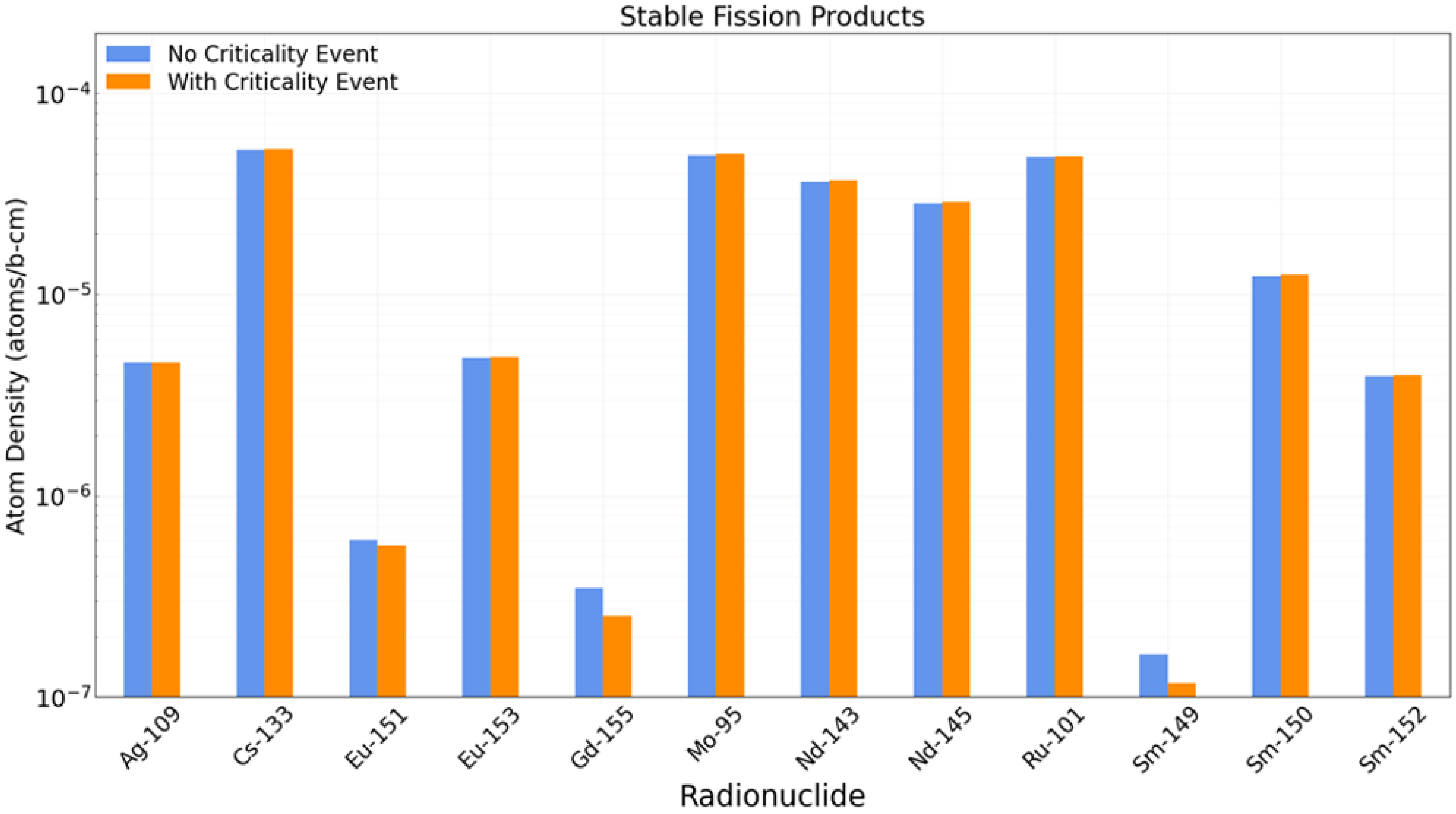
Performance Assessment Analyses

- Waste package fails at 9,000 years after repository closure; water enters the waste package; quasi steady-state criticality event begins
- Power of criticality event ranges from 1 to 4 kW; limited by moderator density and assumes sub-cooled (non-boiling) conditions
- Duration of criticality event is 10,000 years
- Studied changes in radionuclide inventory at 20k years resulting from 2.47 kW event
- Compared repository performance with criticality event to that without criticality event
  - Temperature and liquid pressure at specific observation points within the model
  - Effects of illitization model on permeability
  - Transport of four radionuclides
  - Dose to a member of the public from I-129

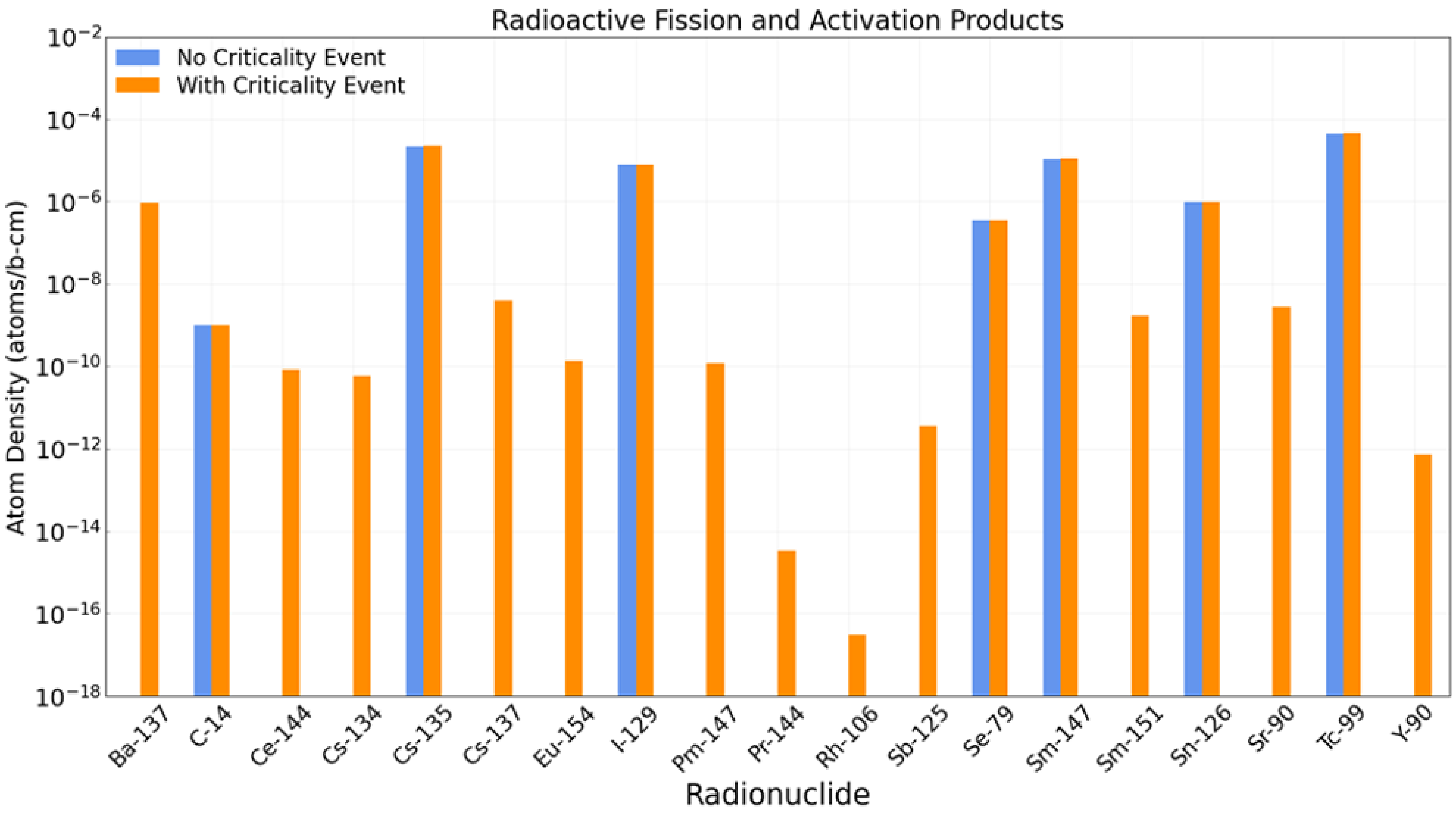
Performance Assessment Analyses – PFLOTRAN model



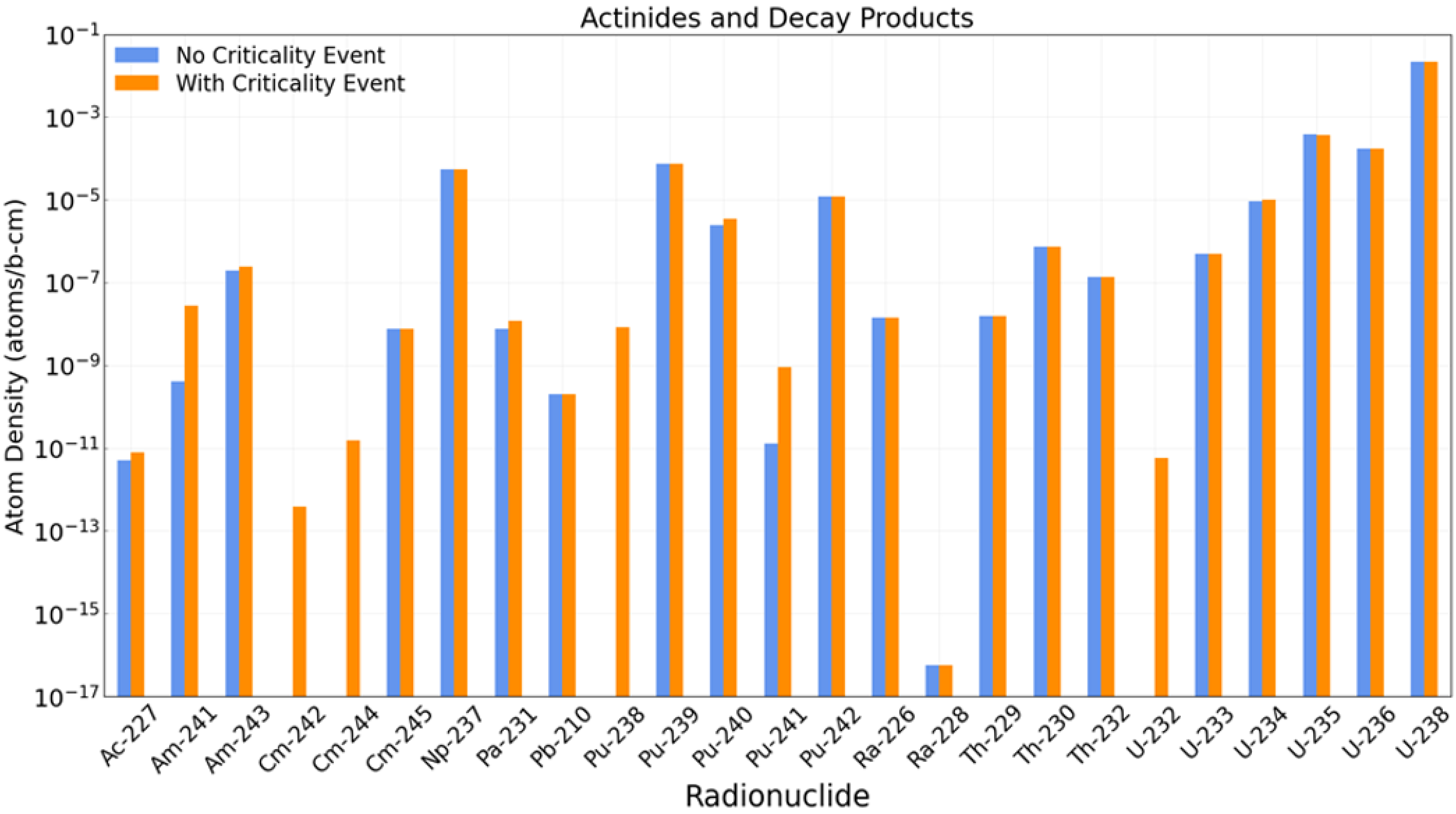
Performance Assessment Analyses – Inventory Changes in Stable Fission Products



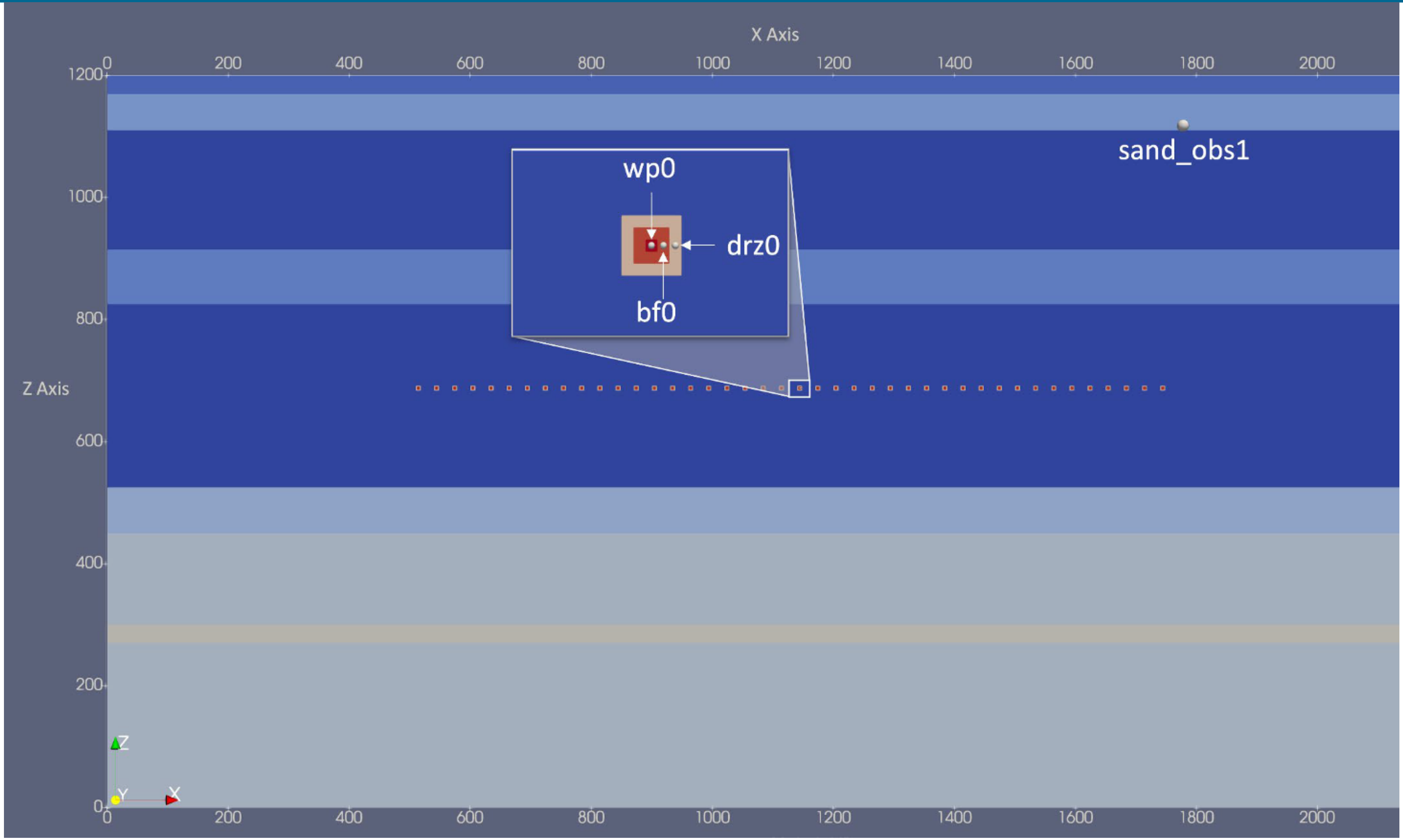
Performance Assessment Analyses – Inventory Changes in Radioactive Fission and Activation Products



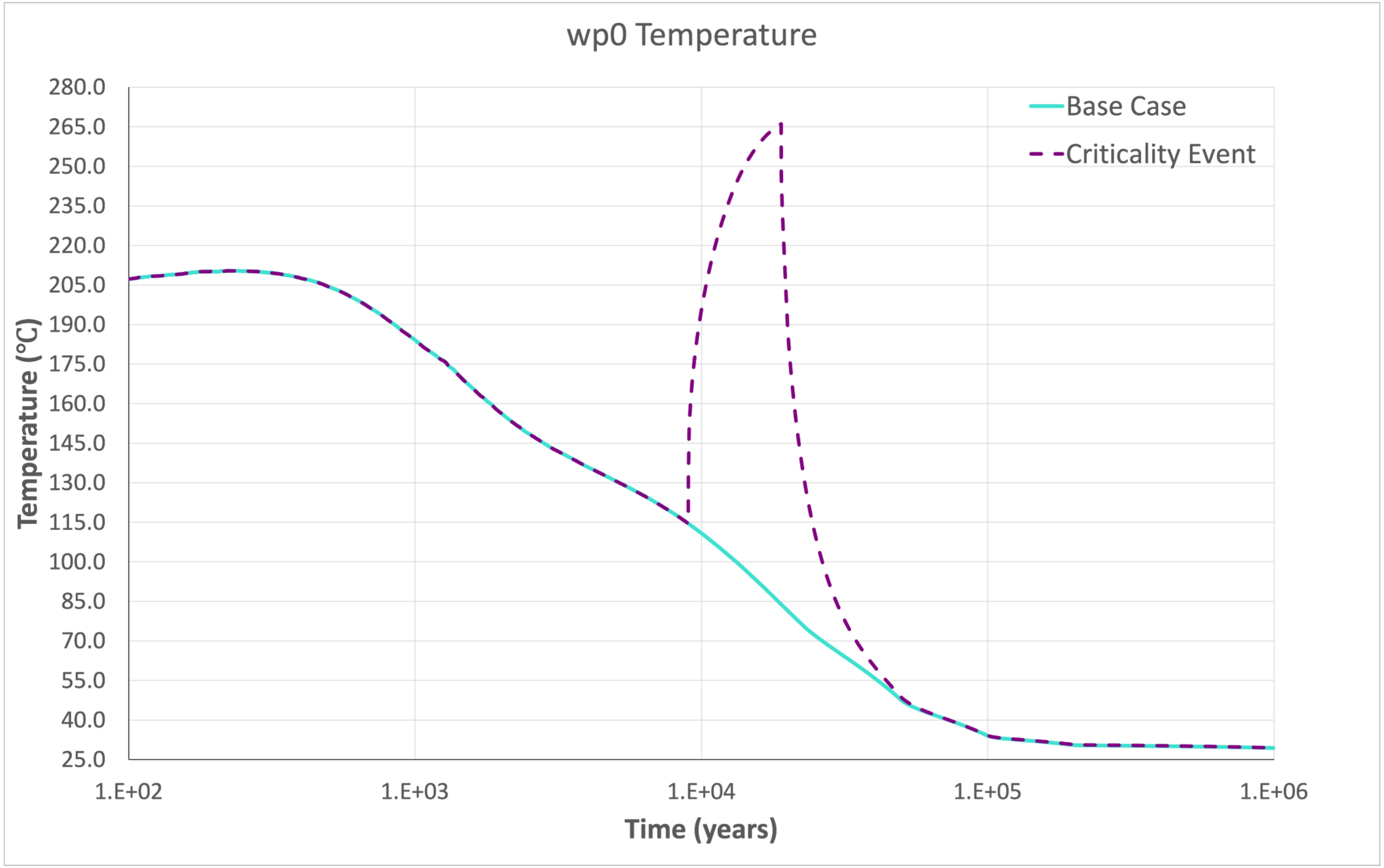
Performance Assessment Analyses – Inventory Changes in Actinides and Decay Products



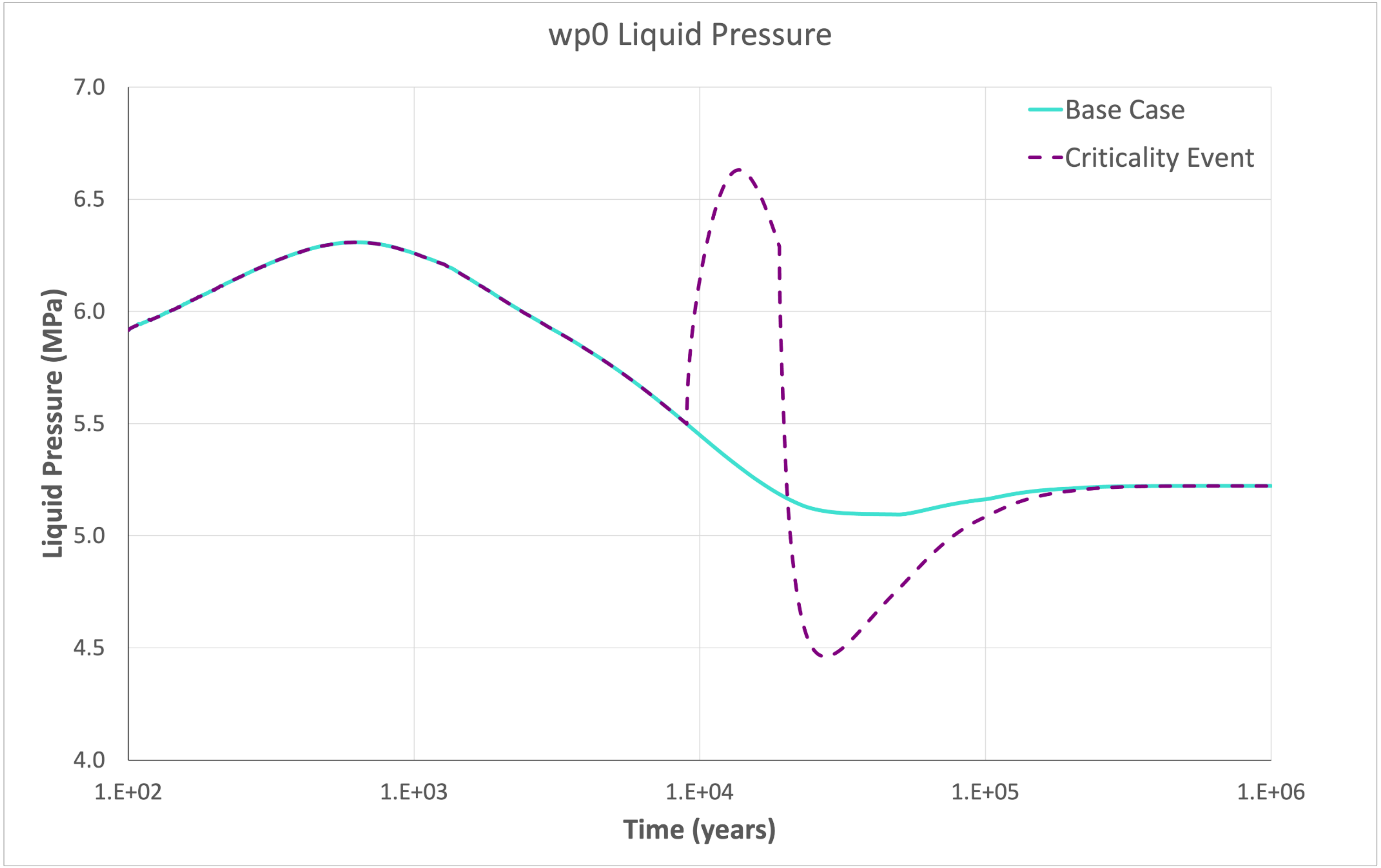
Performance Assessment Analyses – Observation Points



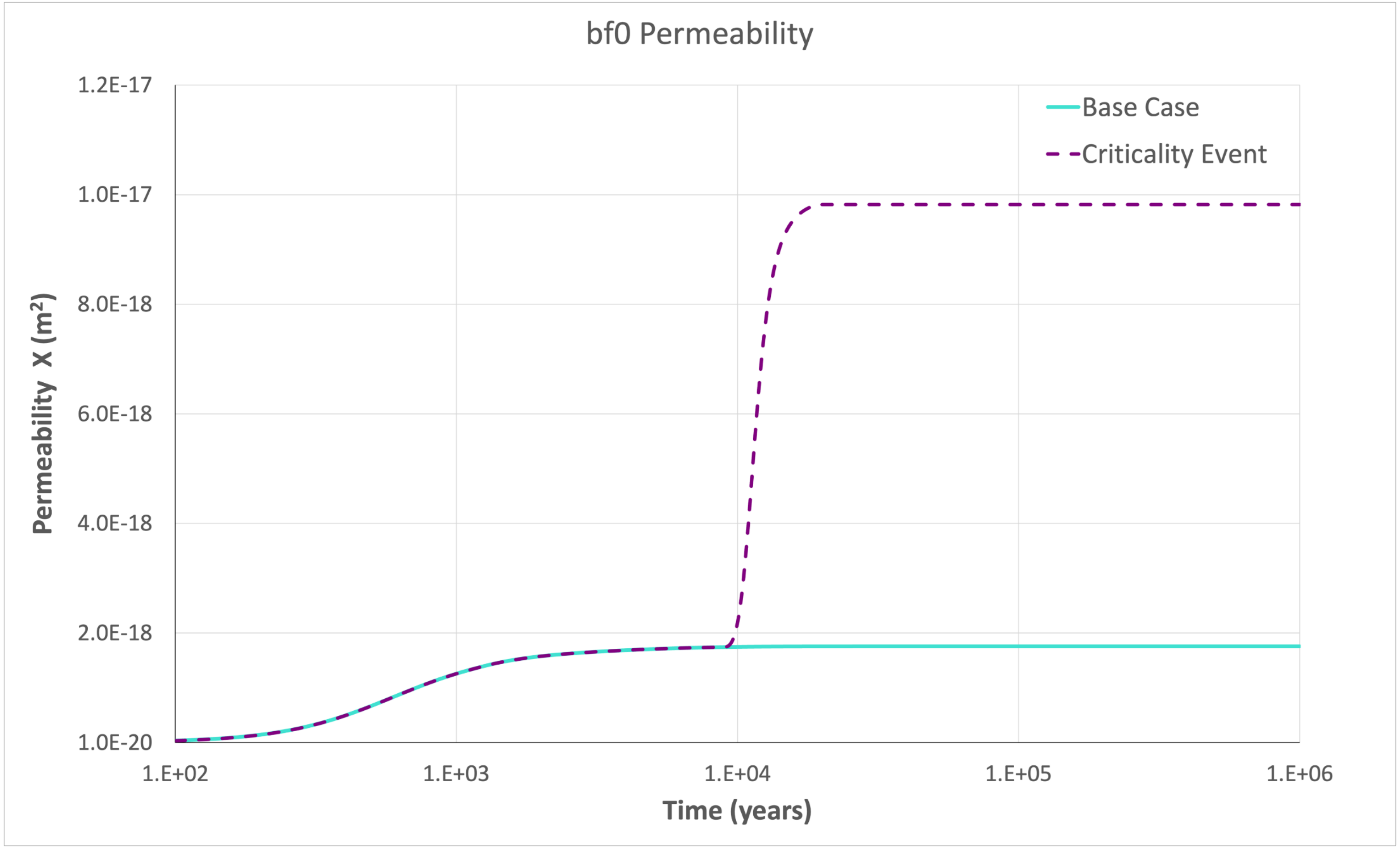
Performance Assessment Analyses – Waste Package Temperature



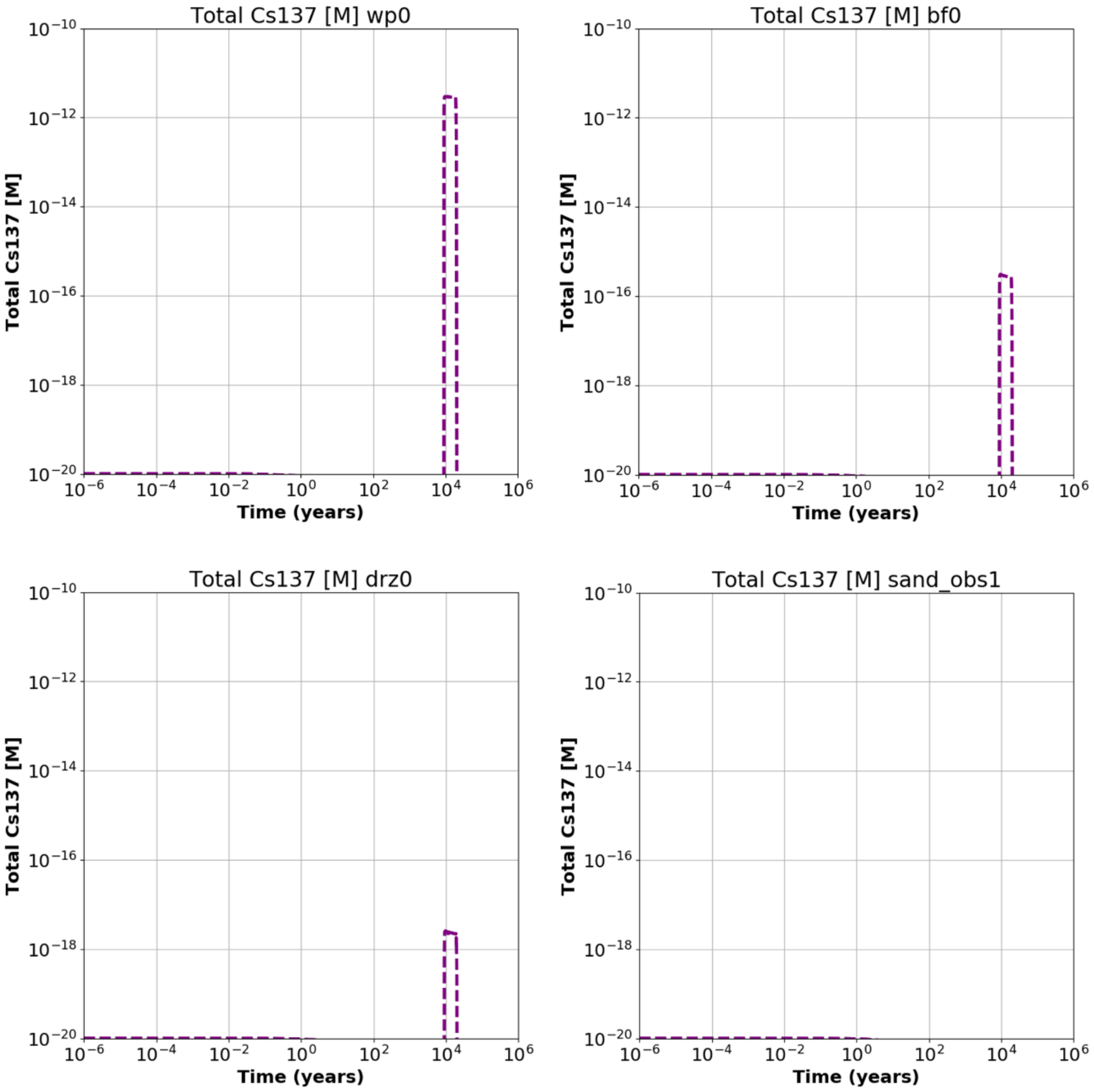
Performance Assessment Analyses – Waste Package Pressure



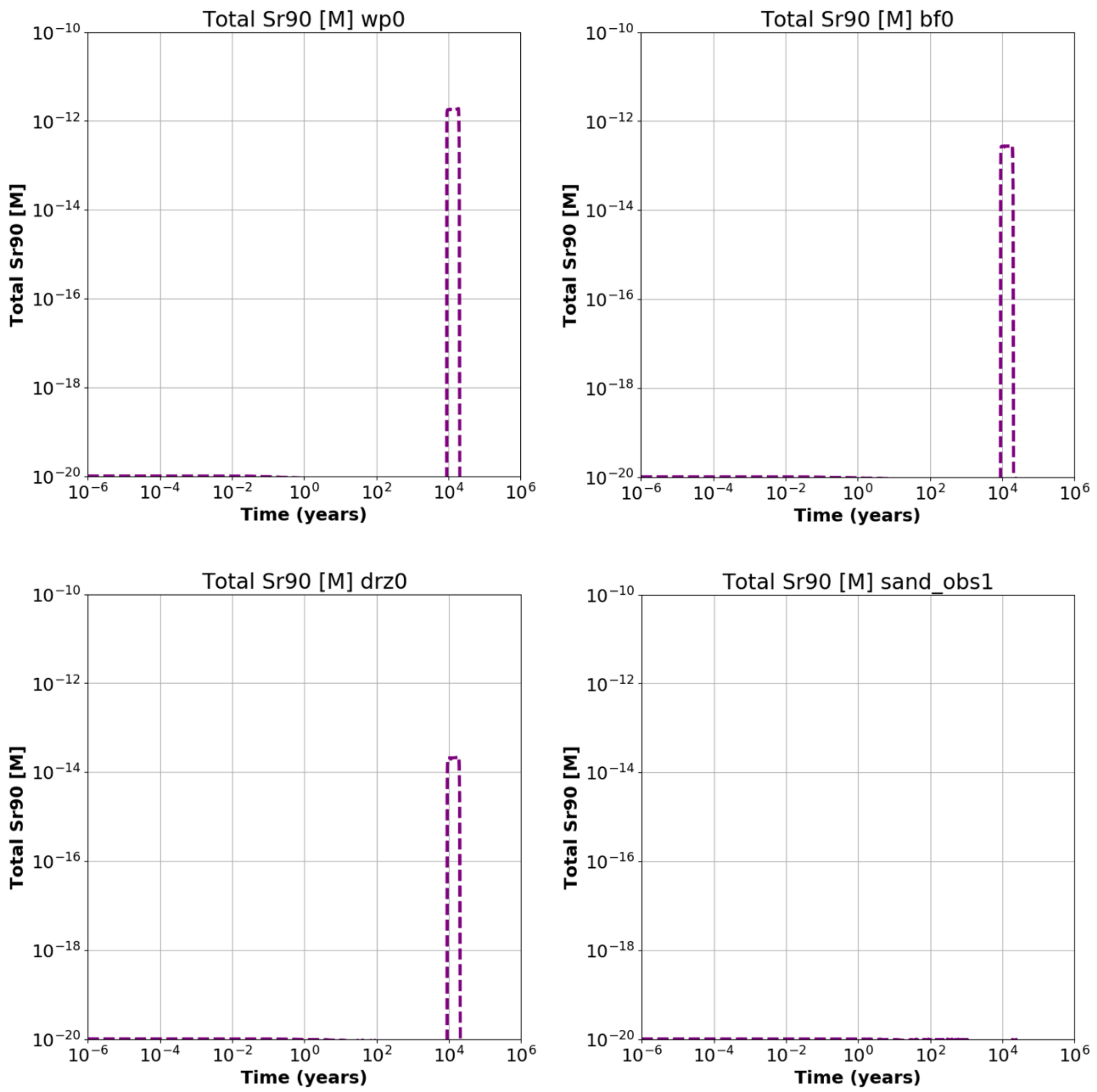
Performance Assessment Analyses – Backfill Permeability (bf0)



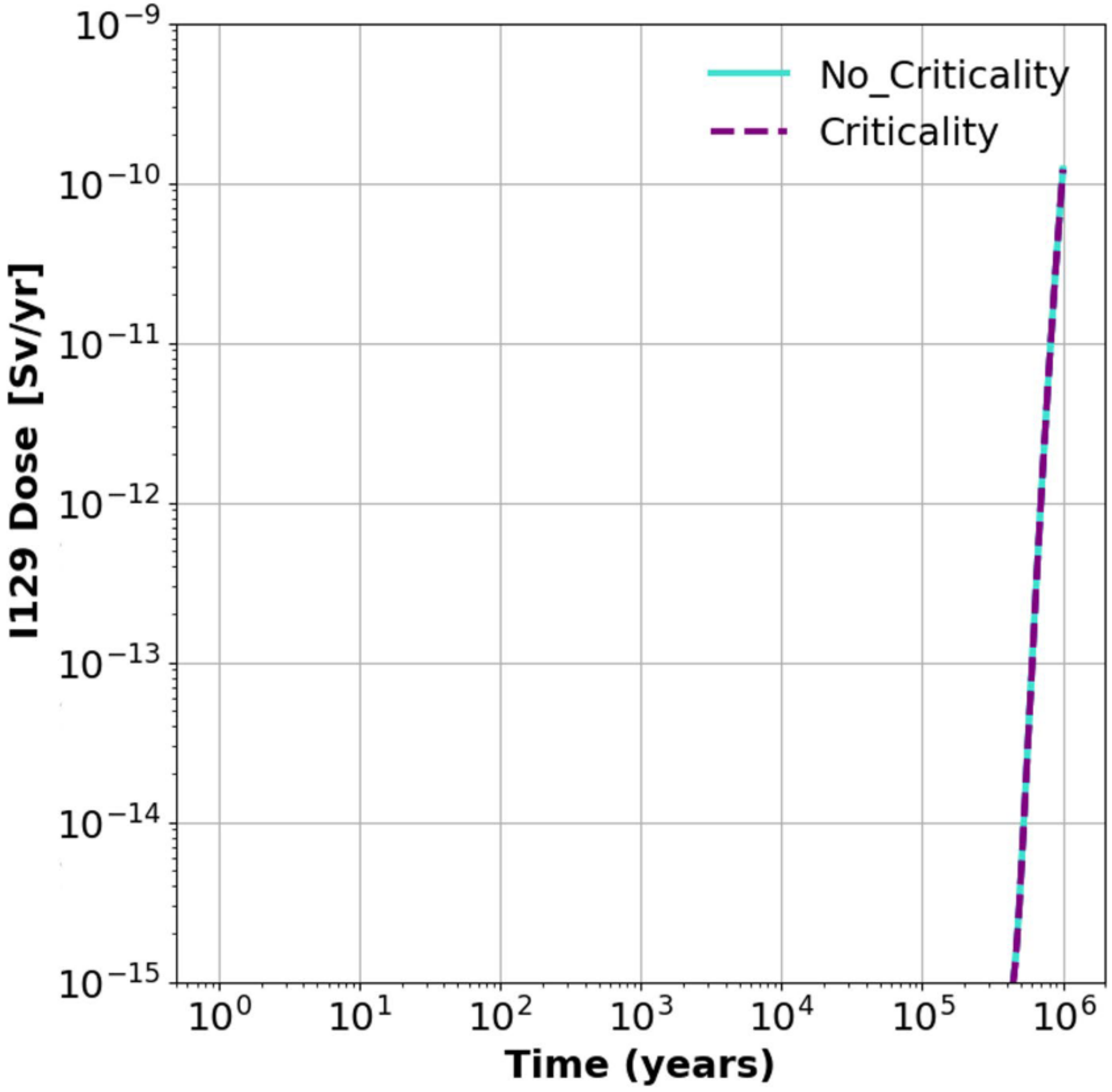
Performance Assessment Analyses – Cs-137 Concentrations



Performance Assessment Analyses – Sr-90 Concentrations



Performance Assessment Analyses – Dose to Member of Public



Further Work

- Analyze neutronics under higher pressure conditions
- Analyze neutronics under boiling conditions
- Incorporate additional FEPs into model of postclosure criticality
- Examine repository-wide uncertainty and variability
- Complete implementation of the grid spacer degradation model

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Questions?