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Influence of Advanced Fuel Cycles on Uncertainty in the Performance of Geologic Disposal Systems

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Do differences in inventory from an advanced fuel cycle impact the uncertainty in mobilization and migration of radionuclides?

Advanced fuel cycle proponents have answered in the affirmative:

- Wigeland, et al. 2011 in *Options Study—Phase II*, FCRD-TIO-2010-000167
  - "…subjectivity to the analysis of disturbed events, especially for the assumptions made as to the nature and consequences of the disturbance, and uncertainty is high for predicting future events. Reduction in inventory lessens the importance of these uncertainties…" (p. 39)
- NEA (Nuclear Energy Agency) 2011 in *Potential Benefits and Impacts of Advanced Nuclear Fuel Cycles with Actinide Partitioning and Transmutation*
  - "As for uncertainty, P&T [Partitioning and Transmutation] can reduce the importance of uncertainties both in normal evolution and in particular those related to hypothetical disruptive scenario that can bring man in direct contact with the disposed waste, since these scenarios seem to be affected by the hazard (radiotoxicity) and not so much by the geology." (p. 66)

Objective of talk is examine this question for US from repository perspective

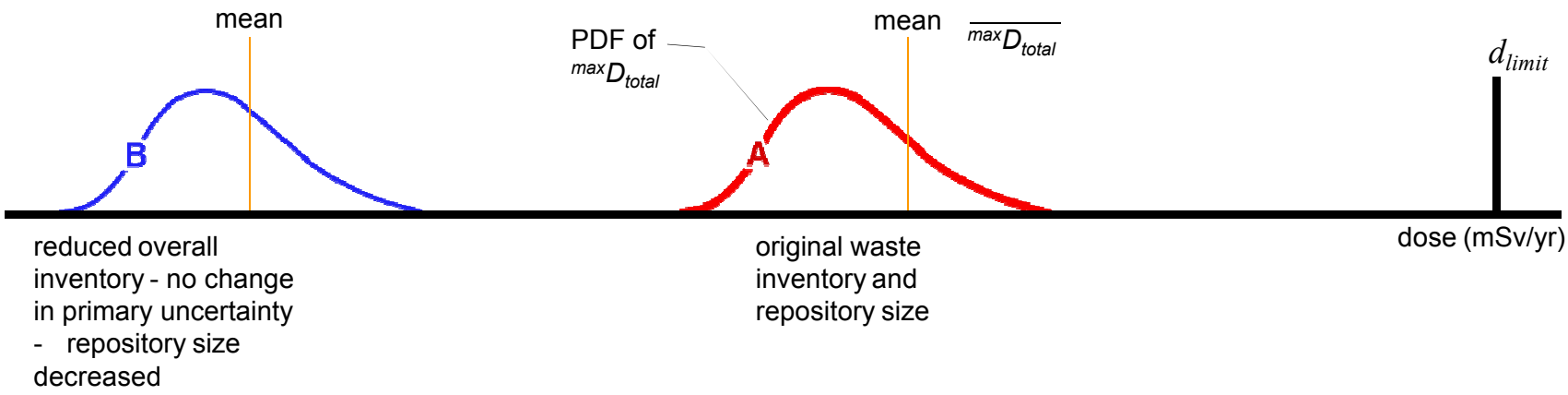
From repository perspective, uncertainty is not reduced by changes in inventory caused by fuel cycle in US context

- Geologic repository is required regardless of the fuel cycle because fission and activation products must be disposed
- Undisturbed conditions and reducing environment,
  - Removal of actinides not expected to change the magnitude of the calculated mean annual dose
- Disruptive conditions in US context
  - Changes in actinide inventory cannot change inherent uncertainty of the event
  - Only dose from groundwater pathway evaluated
  - Removal of actinides may decrease dose somewhat for events that disrupt EBS, but dose from groundwater pathway is still expected to be small and further decrease may not be beneficial

Incremental decrease in uncertainty in US context is not significant

- **Spread in dose is usually caused by parameters unrelated to actinides**
  - Processes and associated parameters related to actinides have only a weak influence; hence incremental decrease is not significant
- **Uncertainty associated with higher temperatures dealt with by establishing design constraints**
  - If constraints met, treatment of uncertainty for coupled processes will be similar and overall performance will be similar
- **Characterization of uncertainty is a major task of a performance assessment for a geologic repository**
  - Will remain a major effort regardless of fuel cycle
  - Actinides removal could diminish characterization of uncertainty for some processes (colloids, solubility, sorption) because of their absence
    - Some characterization necessary to support screening of remnant actinides
    - Modeling components would still be necessary for fission products
  - New, and possibly multiple, waste forms could off-set any benefit
  - Any benefits would only be realized in the situation where entire current inventory of nuclear fuel is recycled

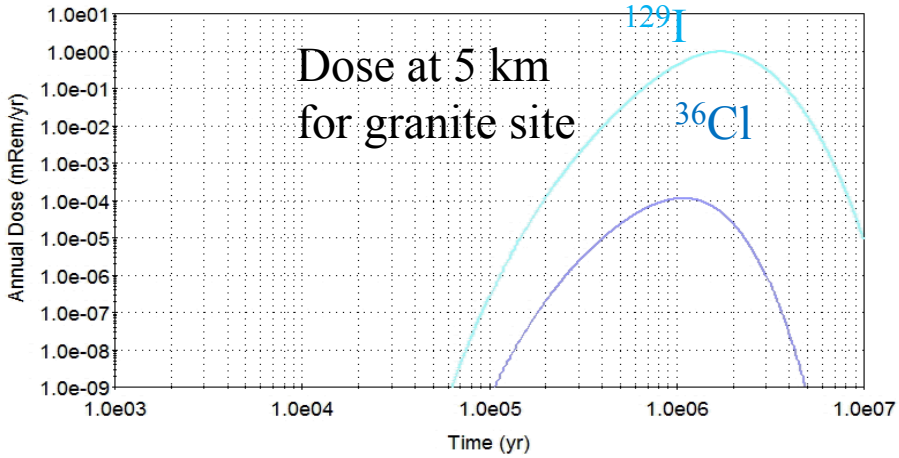
If all uncertainty could be quantified, it could be displayed as the spread of results



- **Here displaying a distribution of the peak dose from multiple simulations**

Fission and activation products most important for determining undisturbed performance

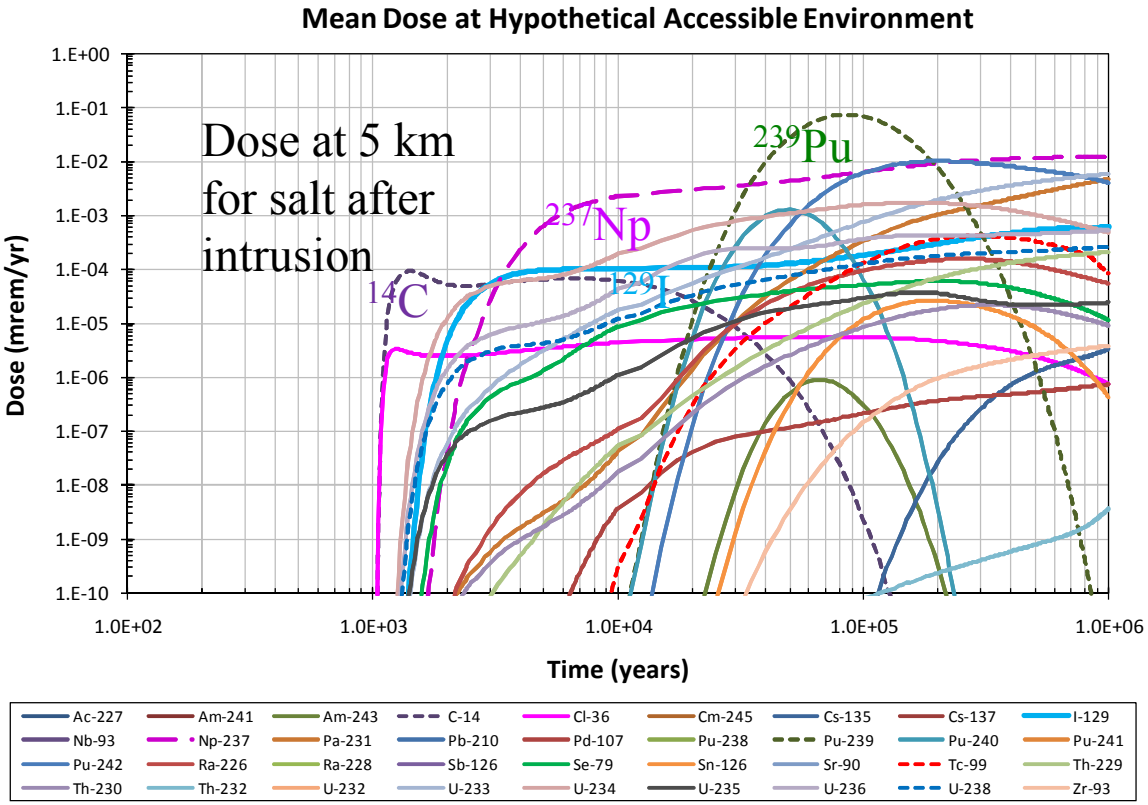
- Geochemistry controls radionuclide mobility and migration
- In reducing environments
  - Actinides are insoluble and sorption is promoted, which limits releases
  - Fission and activation products (^{129}I, ^{36}Cl, and ^{99}Tc) dominate doses
- Actinide removal not expected to decrease the dose for an undisturbed scenario
- Similar behavior noted by other repository programs



Scenario uncertainty in disturbed performance defined in US regulations

- NRC and EPA narrowed focus for anthropogenic disruption scenarios to that of inadvertent human intrusion
  - Defined stylized scenario to avoid undue speculation
    - In stylized case, an exploratory borehole disrupts waste package
    - Evaluate effects of releases via the ground water pathway
    - US does not consider effects to driller or waste being left on surface
  - Purpose of stylized scenario is to test *resilience of repository system*

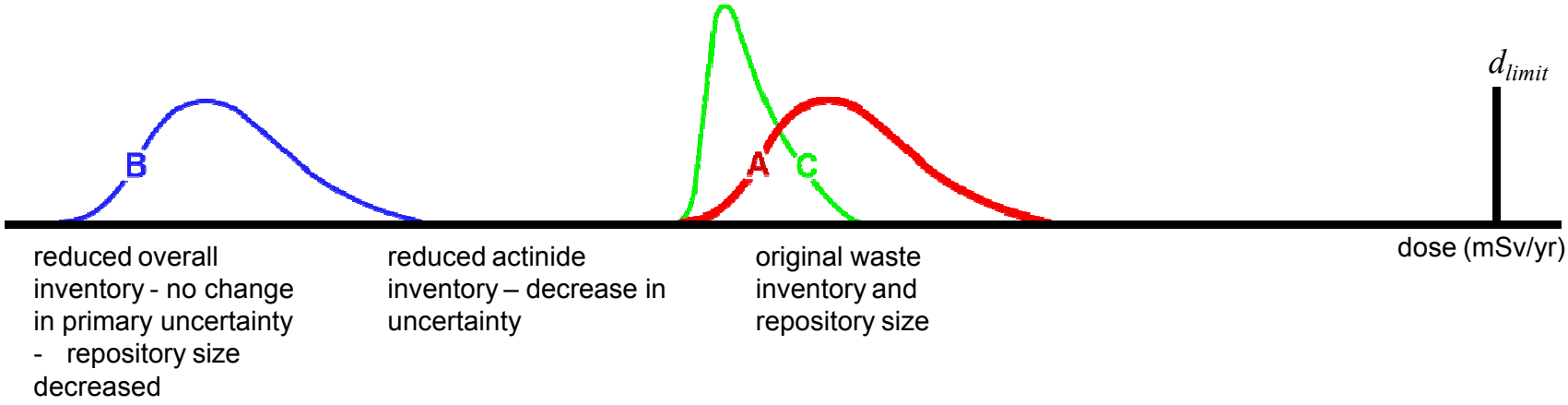
Actinide removal not warranted for salt repository



Peak dose of 0.1 mrem/yr 3 orders of magnitude below 100 mrem/yr limit

The goal is not to endlessly seek to reduce the estimated dose, which could be obtained by using numerous repositories.

Do differences in advanced fuel cycle inventory impact the uncertainty?



From repository program perspective, the difference in advanced fuel cycle inventory do not impact uncertainty

Primary approach here is to qualitatively evaluate incremental changes in FEPs

- Used features, events, and processes (FEPs) to evaluate affects of the two fuel cycle alternatives on uncertainty
  - Feature: An object, structure, or condition that has a potential to affect repository performance
  - Event: A natural or human-caused phenomenon that has a potential to affect repository performance and that occurs over a time interval that is short compared to the period of performance
  - Process: A natural or human-caused phenomenon that has a potential to affect repository performance and that occurs during a significant part of the period of performance
- FEPs are the starting point for assessing the performance of geologic repositories
- Compared qualitatively the disposal of waste from the current once-through open cycle to a fully closed advanced fuel cycle that removes actinides from the waste stream

Characterizing Parameter and Model Uncertainty for Natural Barrier (NBS)

1. Stratigraphic, mechanical, and hydrologic properties of the natural system (unchanged)
2. Hydrologic processes of flow through the natural system (unchanged)
3. Biological processes in far-field (typically excluded)
4. Nuclear criticality in far-field (typically excluded)
5. Thermal processes (at interface with engineered barrier system--EBS)
6. Gas sources (unchanged and typically only important at EBS interface)
7. Geochemical and transport processes influencing
   a) Dissolved radionuclide transport (less radionuclides, but not eliminated)
   b) Sorption (less radionuclides, but modeling not eliminated)
   c) Complexation with carbonates and organics (unchanged)
   d) <u>Colloid-facilitated transport</u> (modeling eliminated but typically of low importance to release)

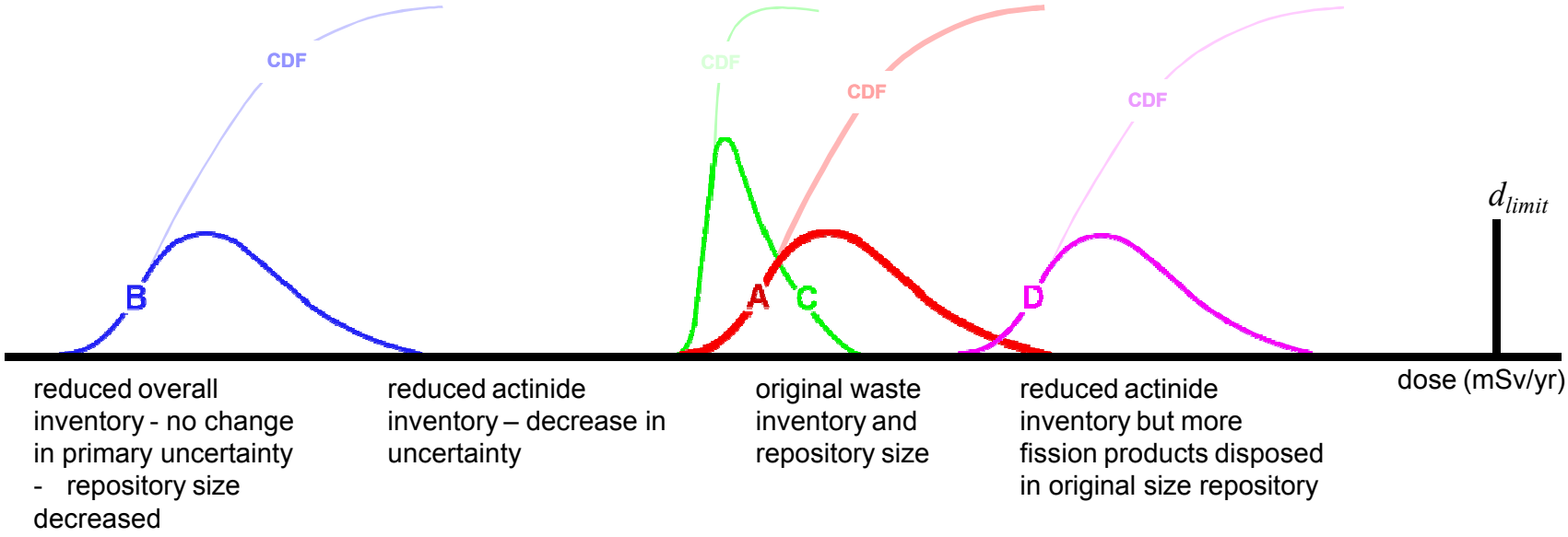
Characterizing Parameter and Model Uncertainty for Engineered Barrier (EBS)

1. Inventory (may be reduced but not eliminated)
2. Nuclear criticality (typically excluded but arguments would be easier)
3. Gas sources from anoxic corrosion, microbial, fission products, and alpha decay (typically excluded in advective dominated crystalline rocks and included with impermeable salt and clay rocks)
4. Hydrologic processes (processes unchanged except for timing of processes because of change in thermal profile)
5. Geochemical and transport processes (same as discussed for natural barrier)

Characterizing Parameter and Model Uncertainty for Engineered Barrier

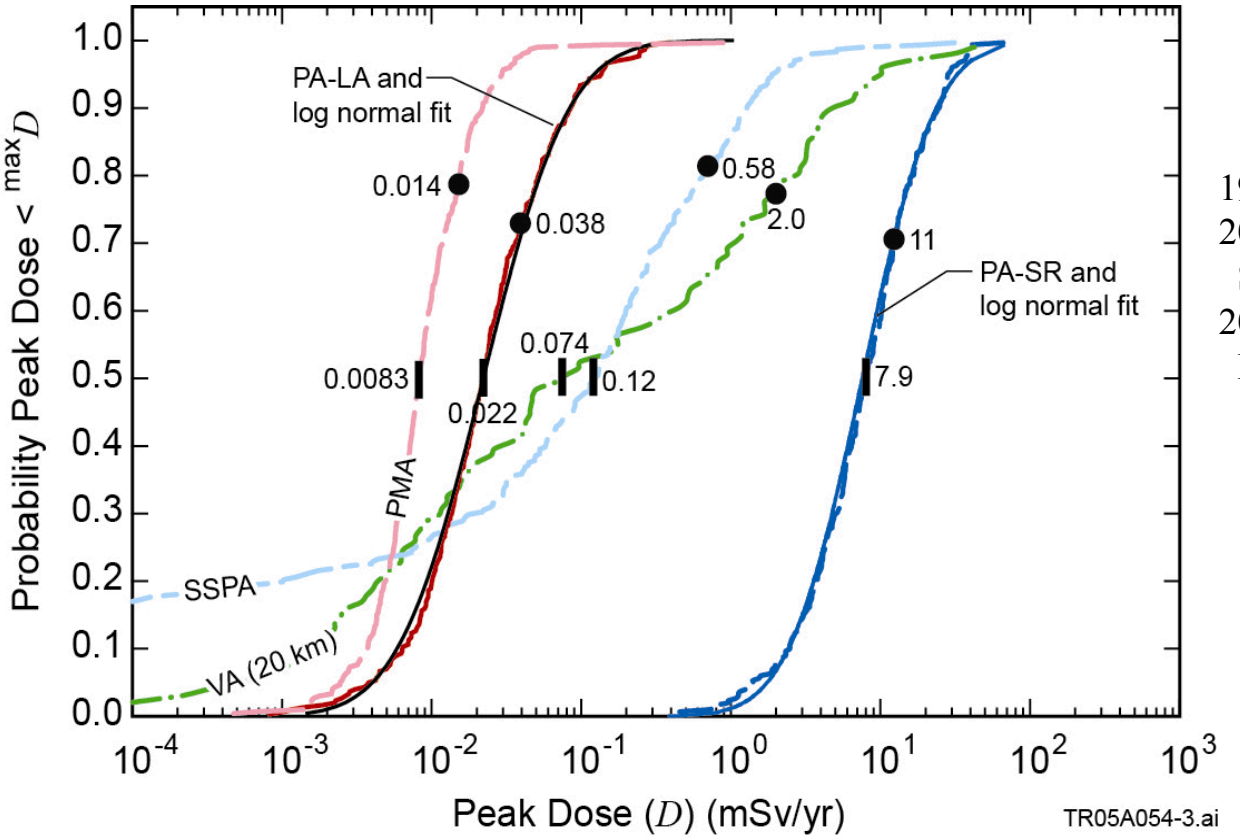
6. EBS integrity
   a) Waste package degradation (unchanged)
   b) Degradation of buffer/backfill/seals and other EBS materials (unchanged)
   c) Biological processes enhance degradation (unchanged)
   d) Mechanical processes (gas pressurization from α decay reduced, but typically excluded)
   e) Waste form degradation (unchanged by actinide removal, additional/multiple waste forms could increase)
7. **Thermal effects on EBS components**
   – Influence on thermal output of waste forms is large
   – However, uncertainty treated by setting design constraints on thermally sensitive components of the system
   – Thermal effects are a design consideration (unchanged)

Change in thermal content would allow change in repository disposal volume for repository



- **Reduced actinide inventory would allow disposal of more fission products in repository**
- **The goal is not to endlessly seek to reduce the estimated dose, which could be obtained by using numerous repositories.**

Decrease in peak doses as understanding and modeling sophistication increased



1998 Viability Assessment (VA)
2001 Site Recommendation (PA-SR)
Supplement Science PA (SSPA)
2008 License Application (PA-LA)
Performance Margin Analysis (PMA)

Change in uncertainty was strongly influenced by changes in the description of NBS and EBS uncertainty

Changes in actinide inventory would not be expected to have as strong influence on peak dose and its uncertainty

Most parameters that influence uncertainty were related to the natural environment

- **Viability Assessment (PA-VA) at 10^6 yr**
  - Fraction of waste packages with seepage
  - Transverse dispersion in saturated zone
  - Biological conversion factor for dose
  - General corrosion rate of outer layer of container (Alloy 22)
- **Site Recommendation (PA-SR) at 10^6 yr**
  - Calibrated property set for unsaturated zone
  - Uncertainty in water usage at the receptor
  - Flow fracture velocity in saturated zone
- **Compliance Analysis (PA-LA) at 5×10^5 yr**
  - Igneous intrusion rate
  - Temperature dependence of corrosion rate of Alloy 22
  - Uncertainty in velocity in saturated zone

Conclusions

- Advanced fuel cycles, in combination with partitioning and transmutation, which remove actinides or that use advanced fuels, will not materially alter
  1. Repository performance,
  2. Spread in dose results around the mean,
  3. Modeling effort to include significant FEPs in the performance assessment, or
  4. Characterization of uncertainty required for natural or engineered barriers in the US regulatory environment.
- The combination of the NBS and EBS provide a geologic disposal system that mitigates the unknowns of scenario uncertainty and model uncertainty
  - For example, the influence of uncertainty in waste form behavior is diminished because other barriers often control the release

BRC had similar finding

- **From the U.S. Blue Ribbon Commission on America's Nuclear Future :**

  If and when technology advances change the balance of market and policy considerations to favor a shift away from the once-through fuel cycle, that shift will be driven by a combination of factors, including—but hardly limited to—its waste management impacts. *In fact, safety, economics, and energy security are likely to be more important drivers of future fuel cycle decisions than waste management concerns per se* (emphasis NOT added)