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Criteria for Criticality in Geologic Media

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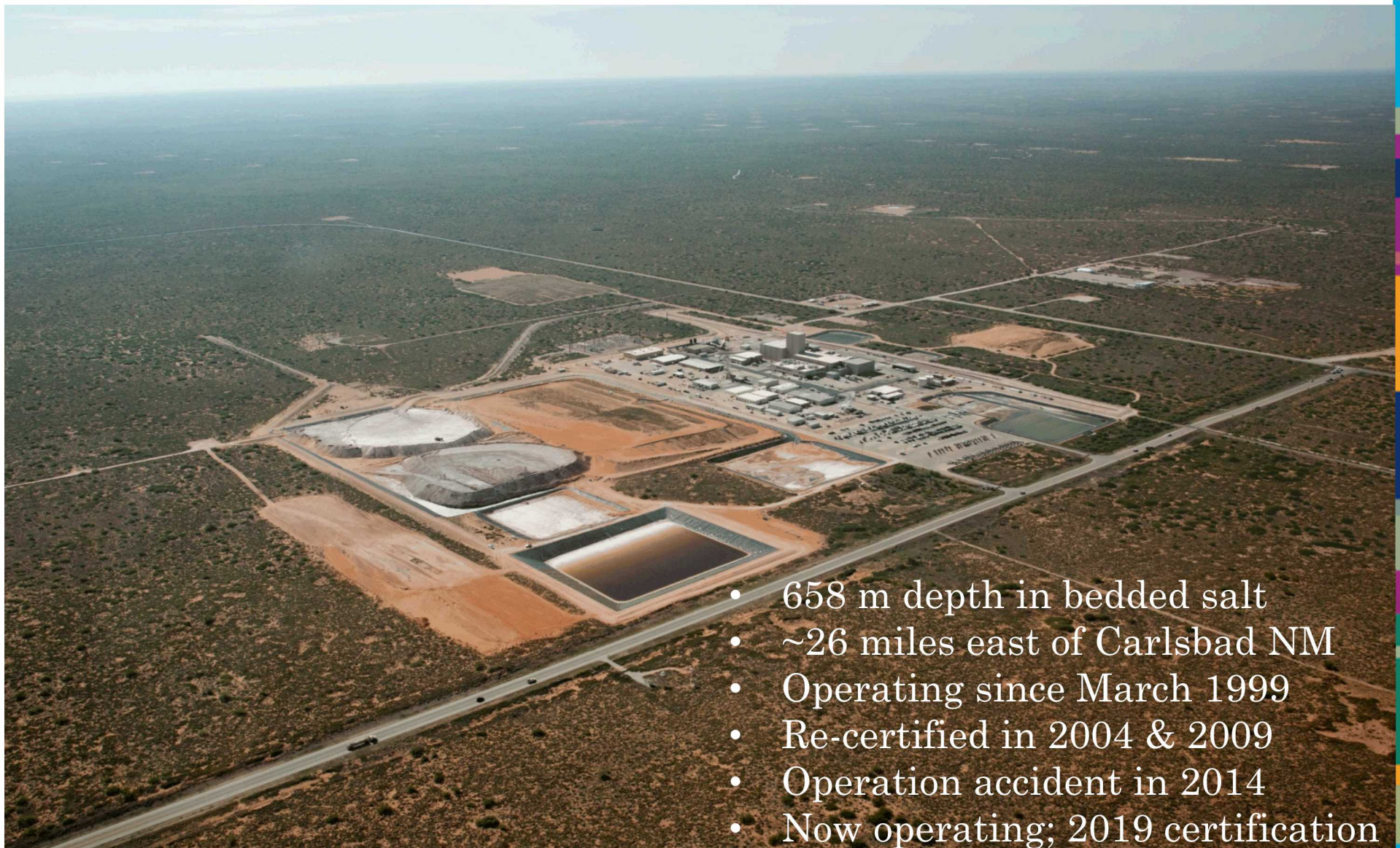
Update to criticality scenario screening is necessary at WIPP because of waste changes

- Waste Isolation Pilot Plant (WIPP) in southern New Mexico is certified to dispose of transuranic (TRU) waste
- In past, concern of criticality in TRU waste was low because of low initial concentration of fissile Pu and U
- Some TRU waste now destined to WIPP includes fissile Pu in high concentrations (but still with low mass in each container)

Talk discusses WIPP and pathways to criticality in addition to neutronic criteria discussed in paper

- Background on WIPP
  - Geology
  - Types of containers
- Pathways to criticality
  - Criticality screening criteria
- Neutronic criteria
  - Updates previous analysis of homogeneous mixtures used for compliance certification application in 1996
  - Includes new work on heterogenous mixtures

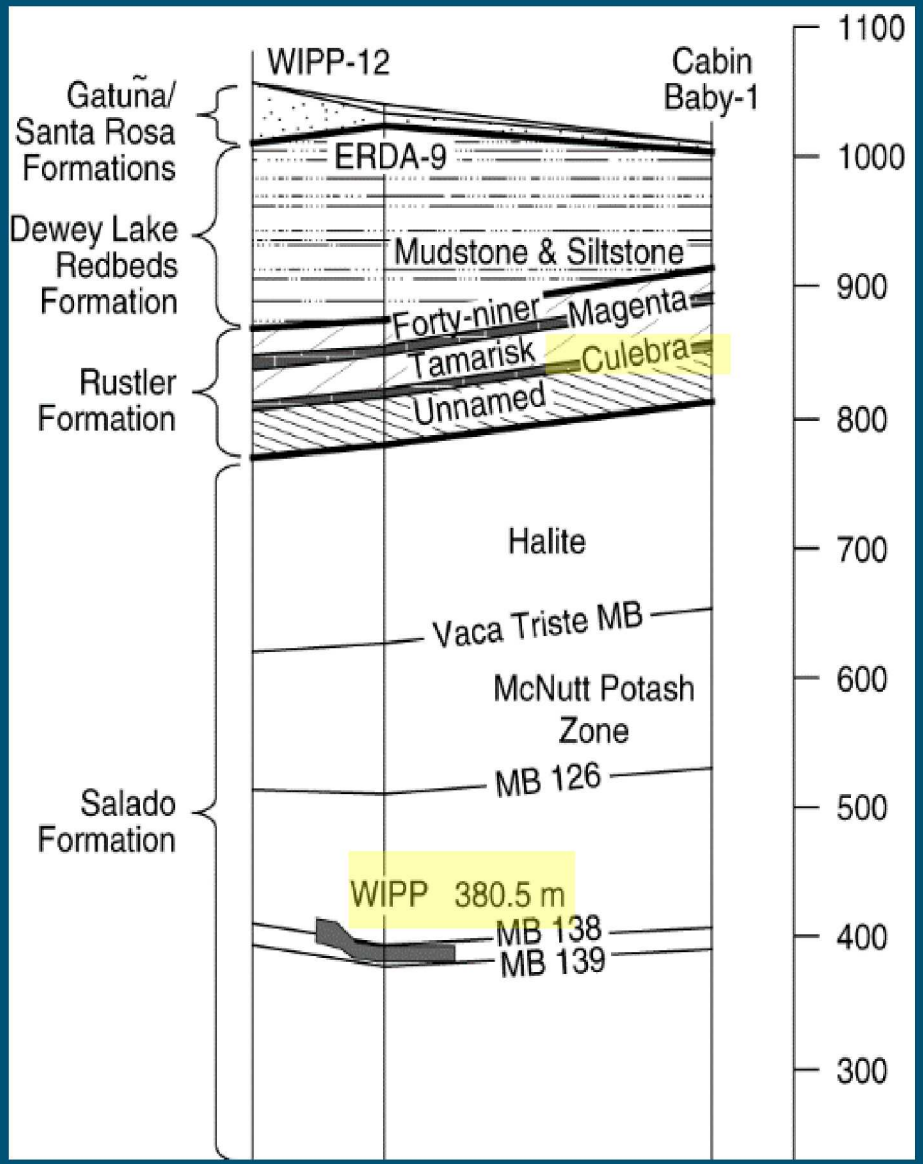
WIPP was designed for disposal of TRU waste from defense activities



- 658 m depth in bedded salt
- ~26 miles east of Carlsbad NM
- Operating since March 1999
- Re-certified in 2004 & 2009
- Operation accident in 2014
- Now operating; 2019 certification

WIPP in ~600-m thick bedded salt layer of Salado Formation

Fractured Culebra dolomite layer located above the repository

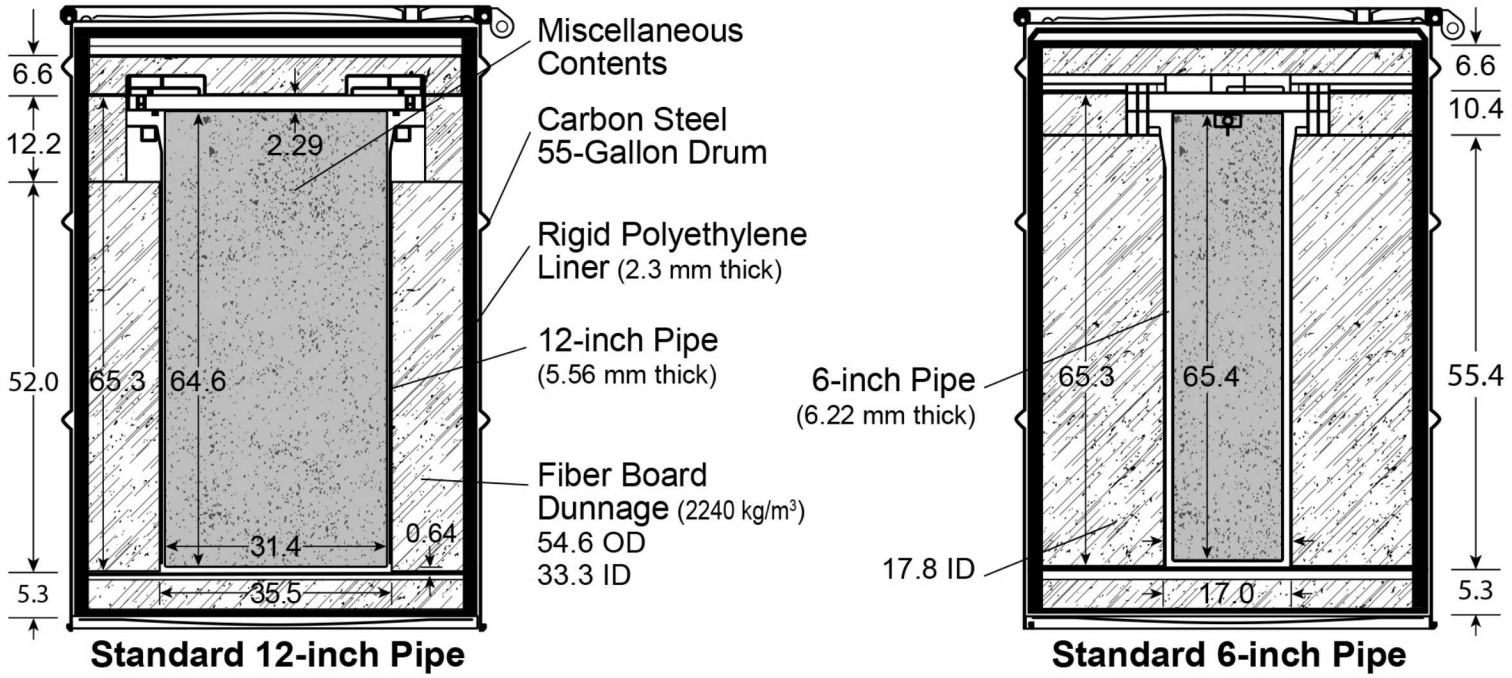


TRU waste from defense activities

- TRU has atomic numbers > uranium
- Radioisotopes in concentrations > 100 nCi/g
- Half life > 20 years
- TRU contaminated material regulated by EPA:
  - Inorganics such as metals
  - Organics such as cellulose
  - Solidified material such as solvents and treatment sludges
- Also contains small amounts of RCRA chemicals regulated by State of New Mexico
- Waste often does not fill drum

Some TRU waste may have high Pu concentration (but limited Pu content)

- Standard pipe overpack container (POC) for miscellaneous content limited to 200 FGE Pu
- < 4% of waste inventory



Emplaced TRU waste in standard drums and standard waste boxes from Idaho in 1999

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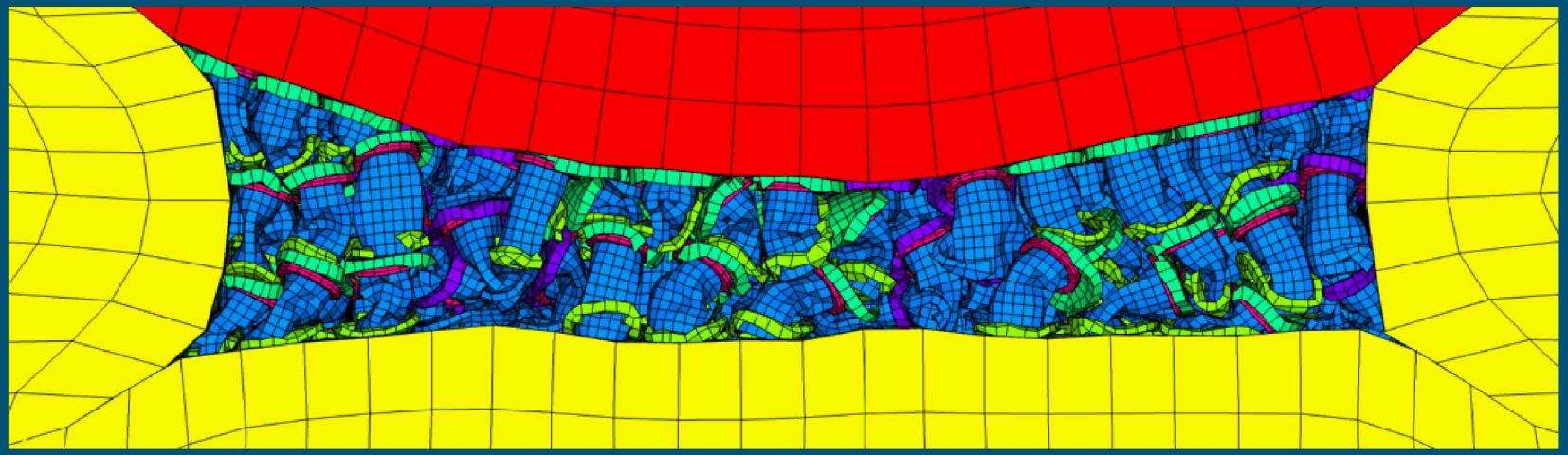
Criticality update has several parts

1. Physical compaction of containers by salt creep



2. Evaluation of hydrologic and geochemical aspects that prevent fissile material from assembling into critical concentrations outside of container
   - Waste degradation, fissile dissolution, transport, fissile precipitation, and adsorption
   - Neutronic criteria necessary for criticality

Screening criticality based on regulatory guidance for disposal

- Should a feature, event or process (FEP) or scenario such as criticality be included in modeling?
- 3 screening criteria for exclusion
  - Exclude irrelevant FEP based on regulatory requirements or guidance
  - Exclude unimportant FEP based on probability of occurrence
  - Exclude FEP with little or no consequence to repository performance (e.g., unimportant to timing and magnitude of cumulative release or dose)
- Regulatory requirements and guidance underlie each exclusion criteria

Probability criterion defined in US disposal regulations

- Criticality considered similar to other FEPs; disposal regulations do not provide separate guidance for criticality
- FEP or scenario with a *mean* probability of occurrence less than 10^{-4} during 10,000 years need not be considered

  Examples:
  - Large meteorite impacts
  - Seismic events in tectonically stable regions

- Probabilities may be based on
  - Frequency of past events
  - Expert judgment (e.g., with expert elicitation)
  - Analog information
  - Regulatory guidance

Estimate of *mean* probability implied by EPA and emphasized by NRC

"…the mean of the distribution range is to be used to screen an event from the performance assessment."

- Use of probability to screen criticality after disposal differs substantially for screening criticality during operations when humans are present

- During operations, rationale for eliminating criticality is rule-based (ANSI/ANS-81) to demonstrate impossibility of criticality to ensure human safety

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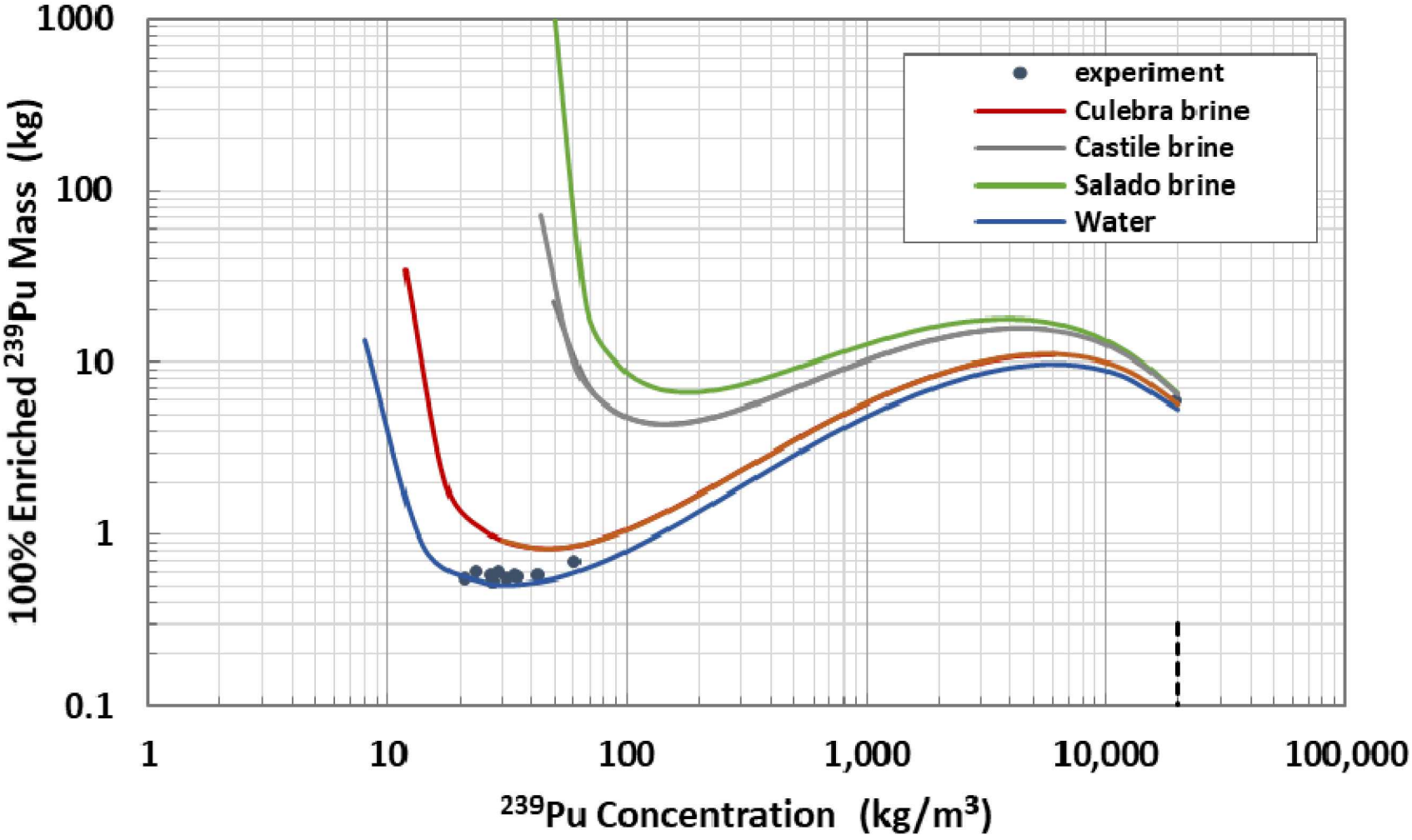
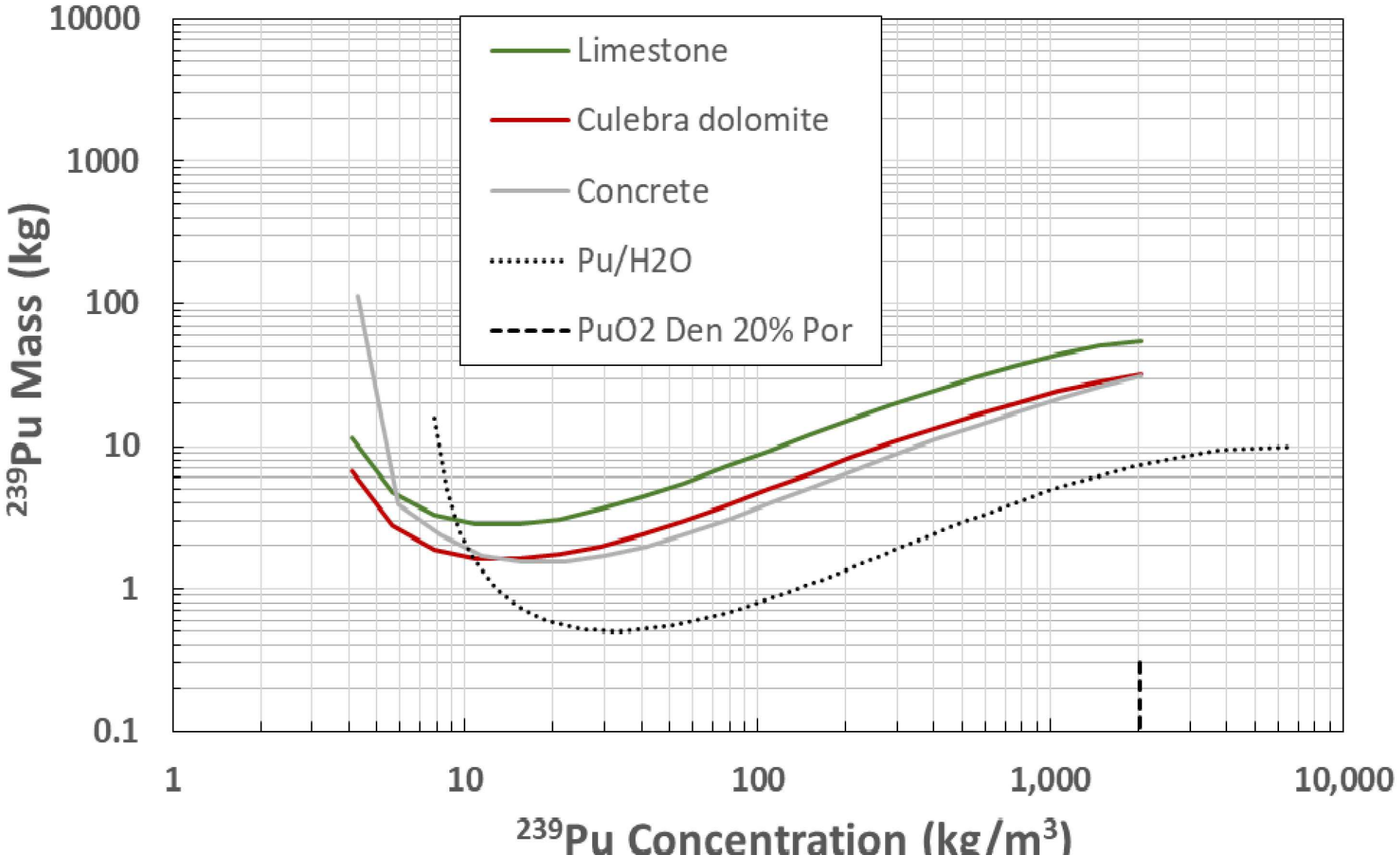
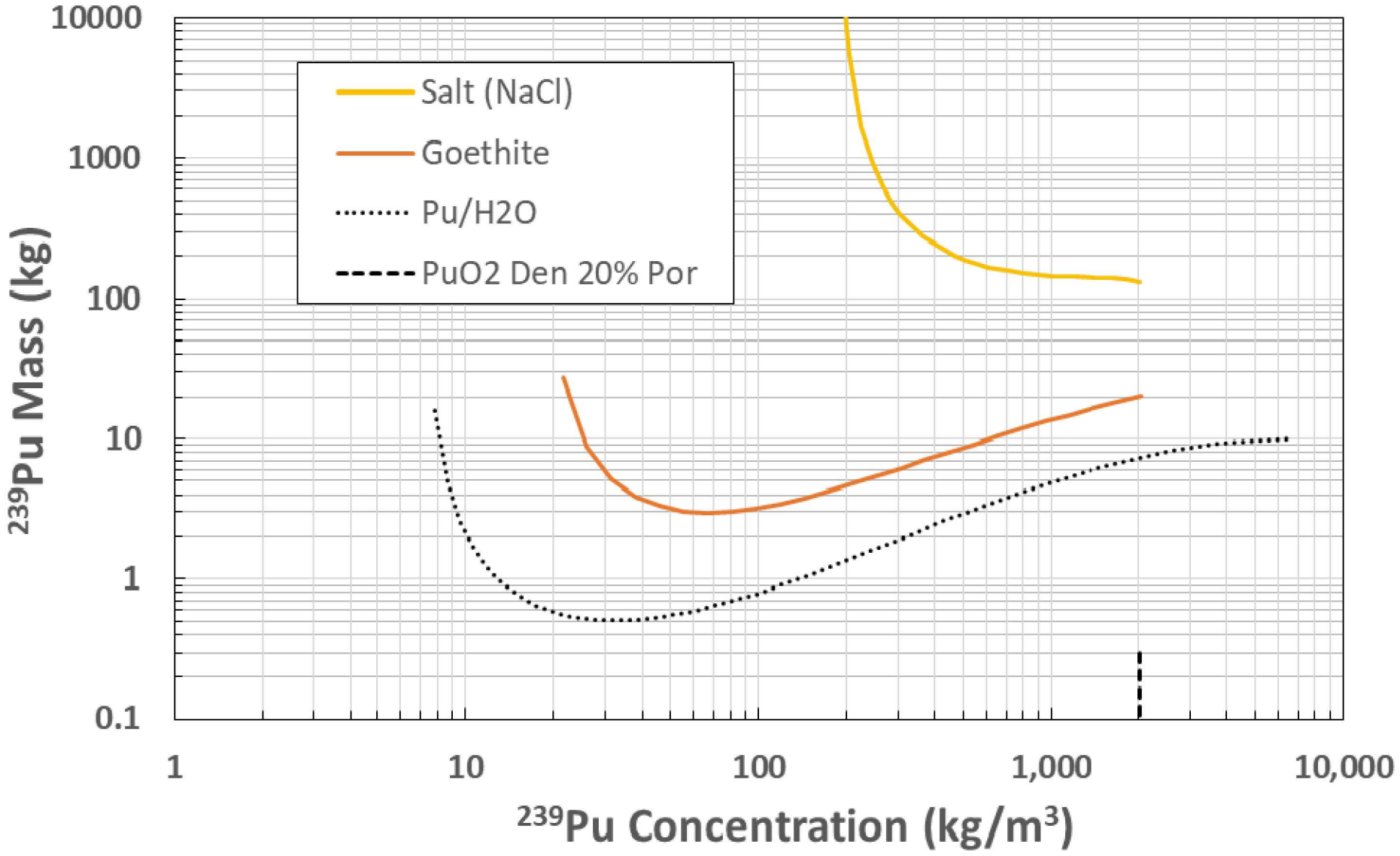
WIPP brines increase ^{239}Pu mass and concentration required for criticality in homogeneous spherical system



Adding carbonate media to Pu/H_2O sphere increases Pu mass but decreases concentration necessary for criticality

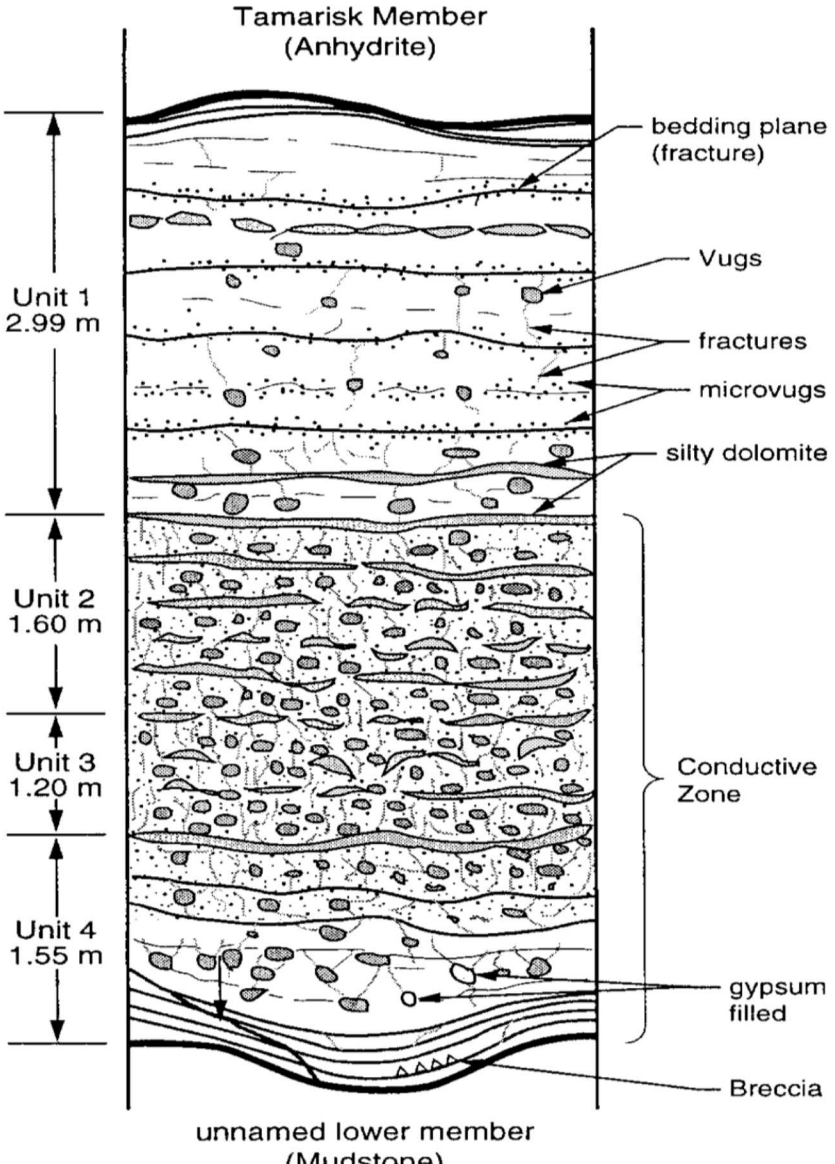


Geologic media rich in Fe and Cl increases both Pu mass and concentration necessary for criticality

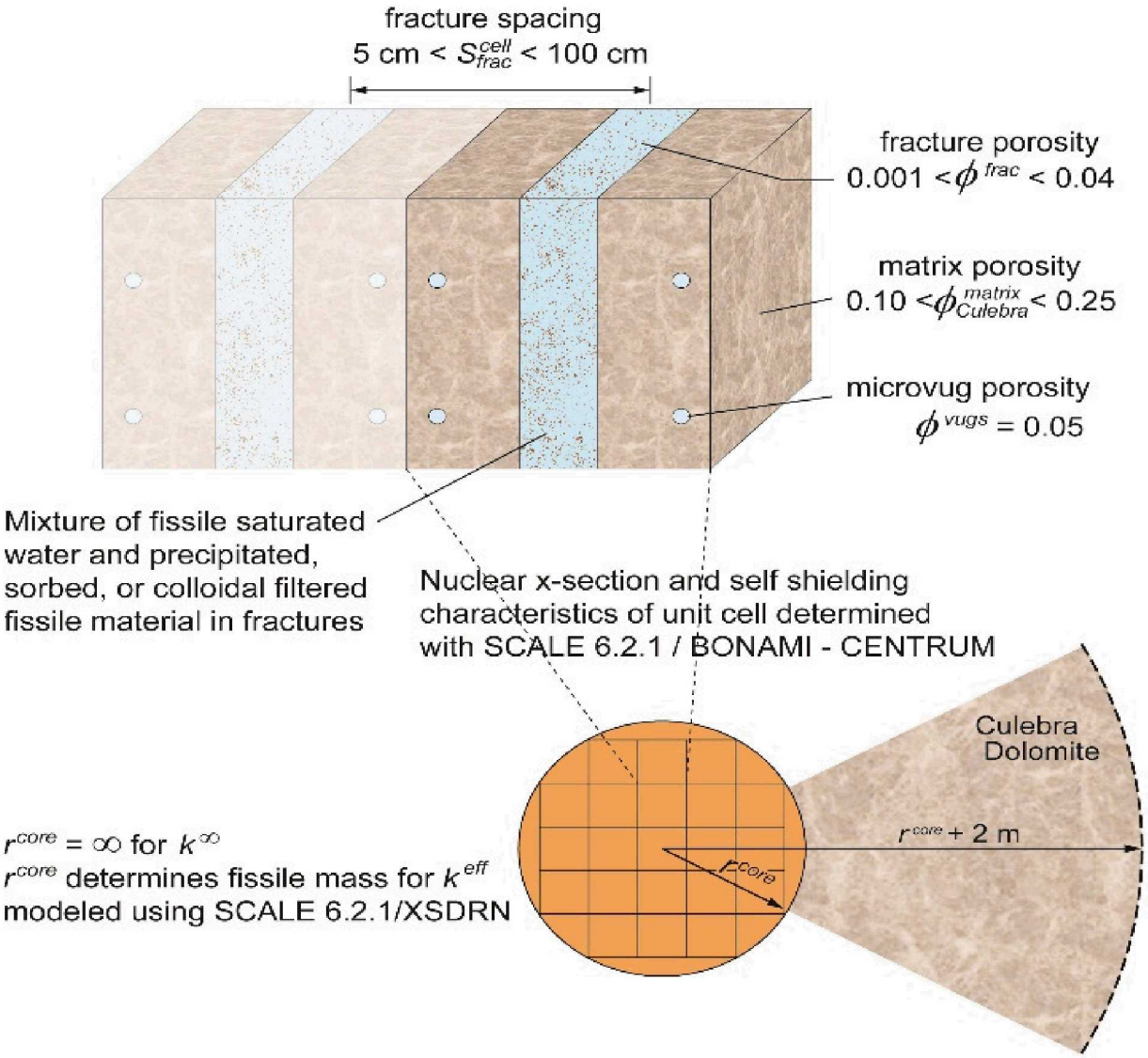


Culebra dolomite has heterogeneous features such as fractures and vugs

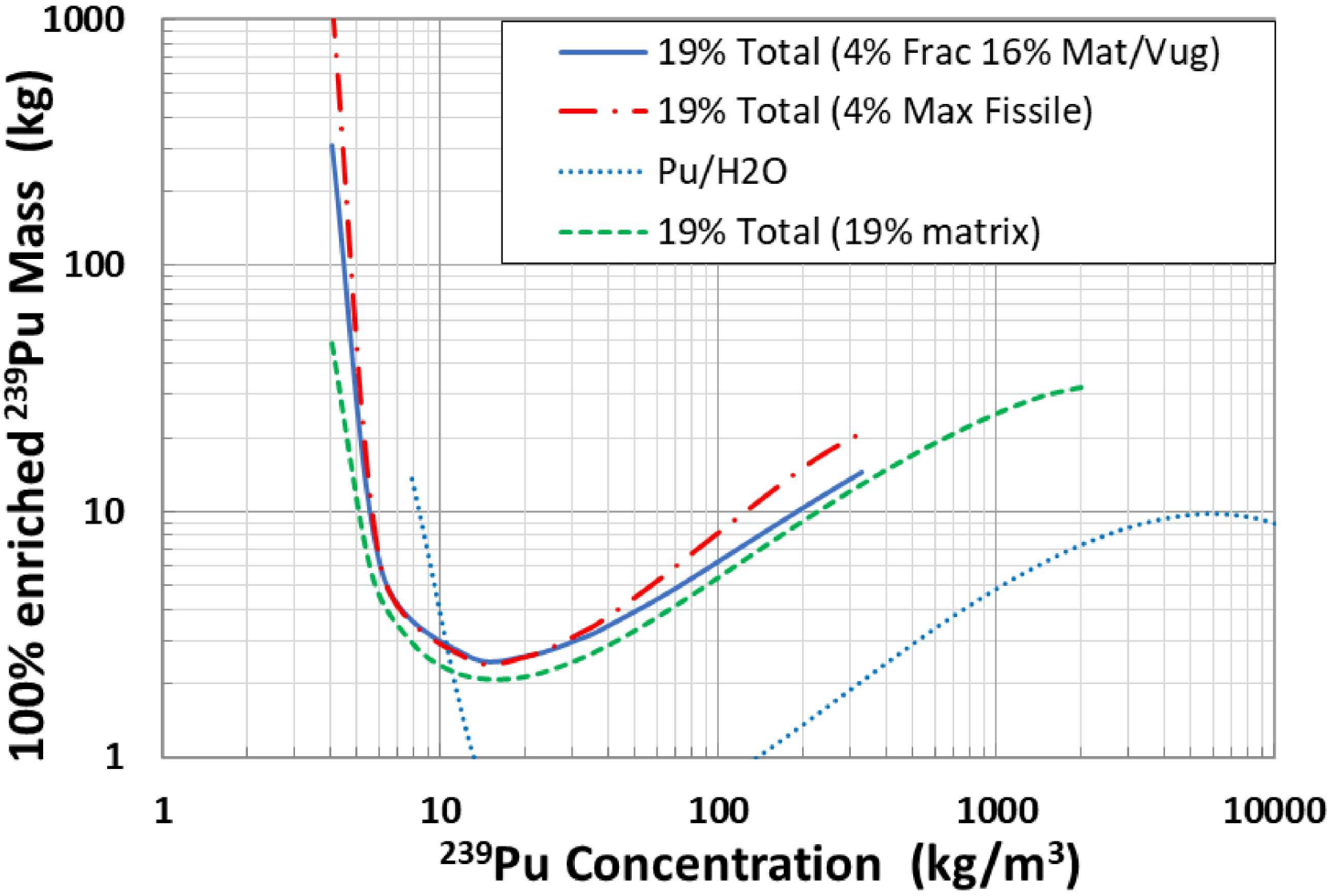
- Matrix porosity
  10% to 25%
- Vug porosity ~5%
- Fracture porosity (deposition)
  0.01% to 4%
- Fracture spacing
  1 cm < 5 cm < 100 cm



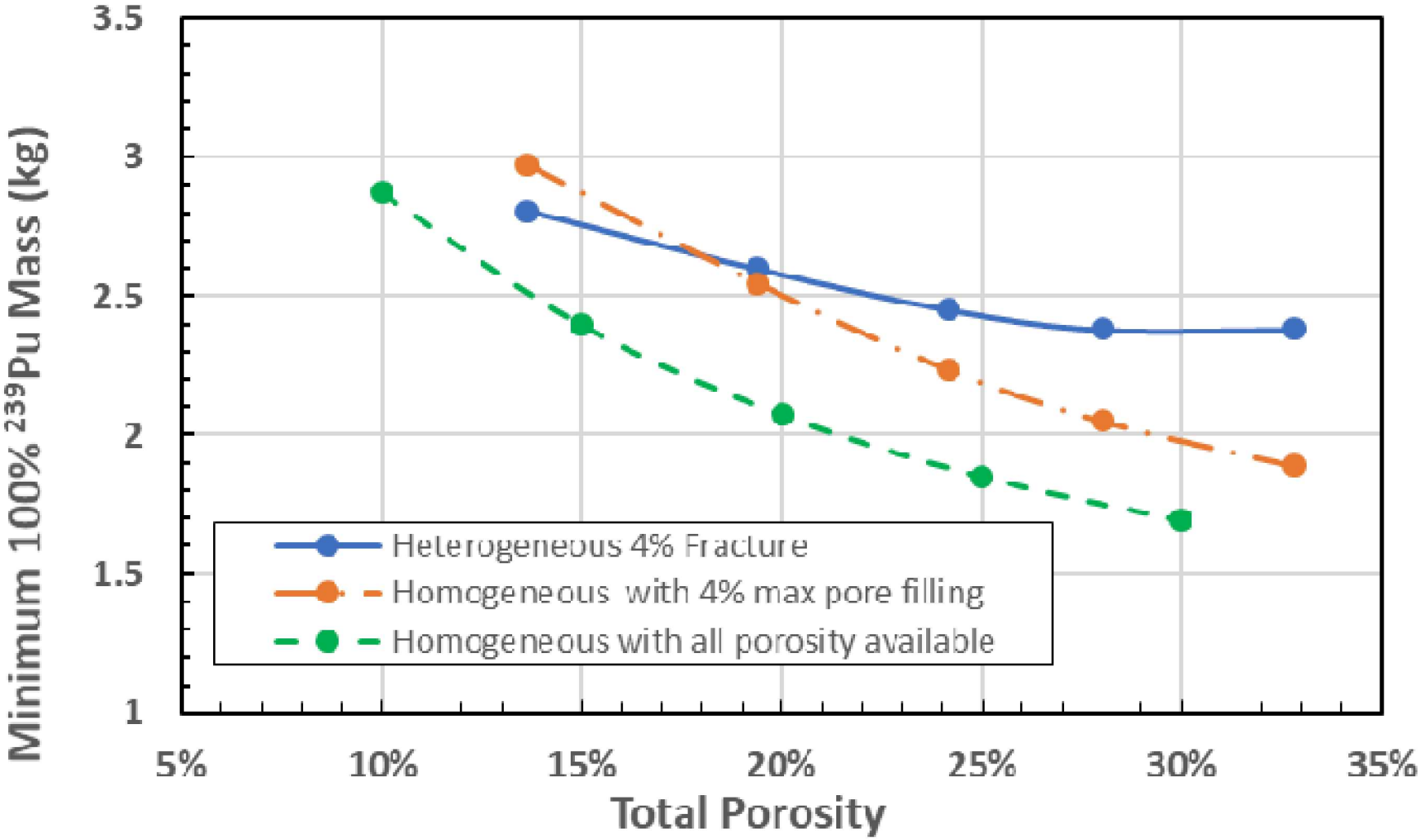
Unit cells of deposition in heterogeneous fractures arranged spherically in SCALE model



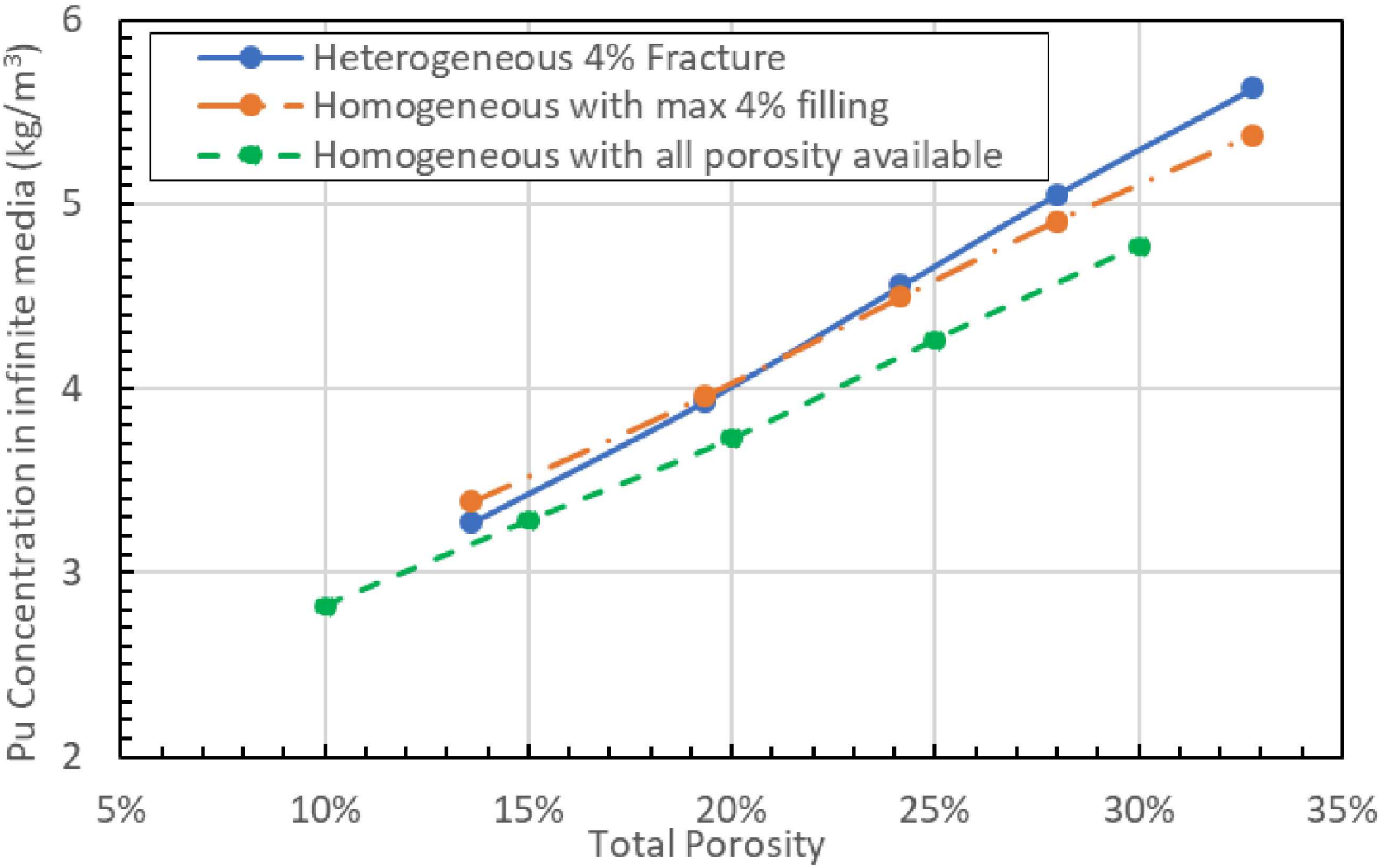
Pu mass in heterogeneous model never less than homogeneous model when all porosity available



In range of interest, homogeneous model with all porosity available for deposition requires less Pu mass



Minimum critical concentration strongly influenced by porosity but not heterogeneity

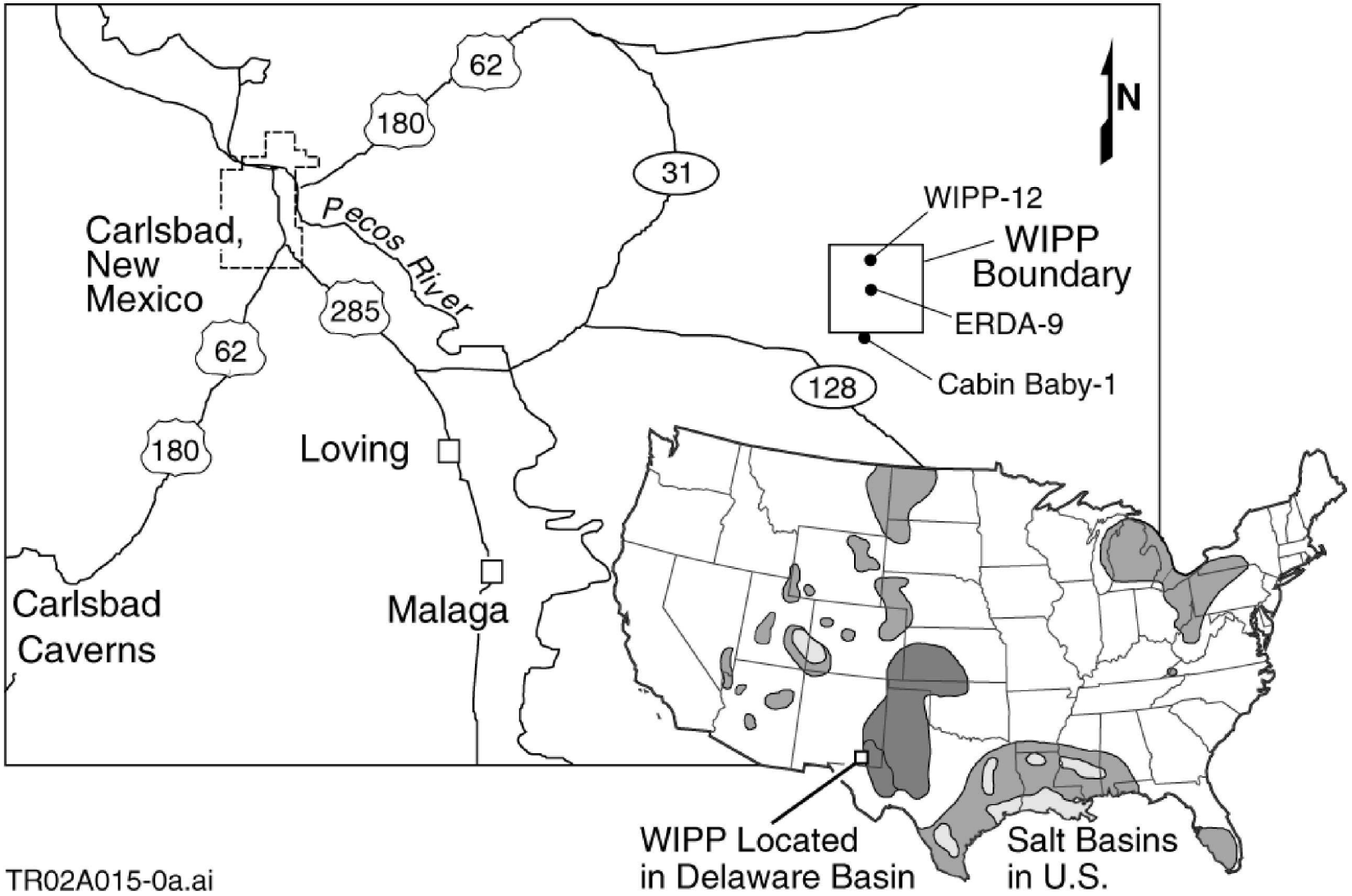


Conclusions

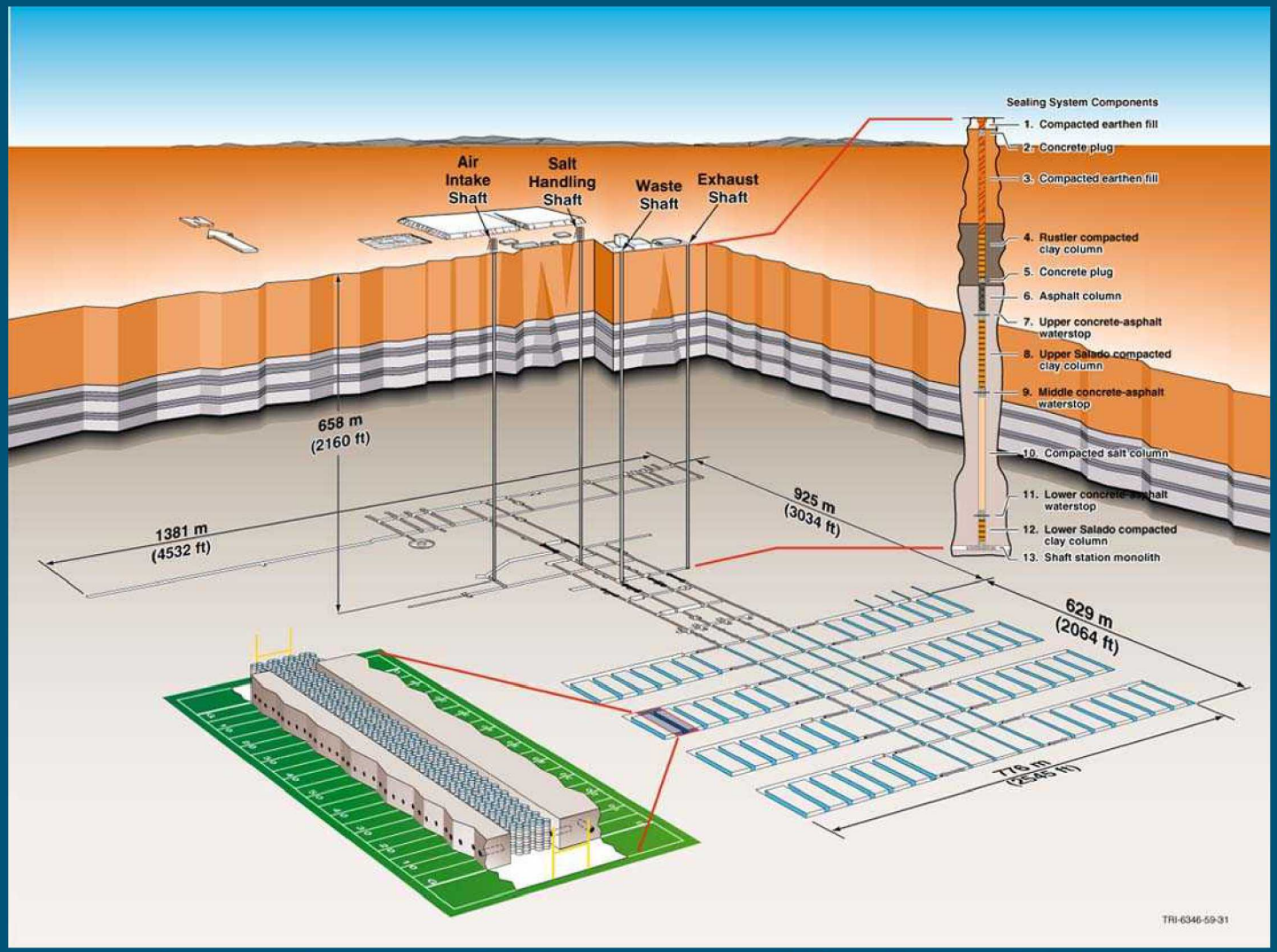
- WIPP brines substantially increase fissile mass necessary for criticality
- Geologic media substantially increases fissile mass necessary for criticality
- Influence of geologic media on asymptotic concentration (infinite media) varies
  - Often geologic media a mild moderator and reduces limiting concentration
  - Salt and rust absorbers increases limiting concentration
- Porosity of the geologic media has strong influence on both the critical mass and concentration
- Homogeneous model with deposition in all the available porosity bounds both the minimum critical concentration and mass of a heterogeneous model
- Heterogeneity important when deposition occurs in only portion of porosity and the total porosity is small (even at high fissile enrichment)

Backup slides

WIPP located Delaware Basin near Carlsbad, NM



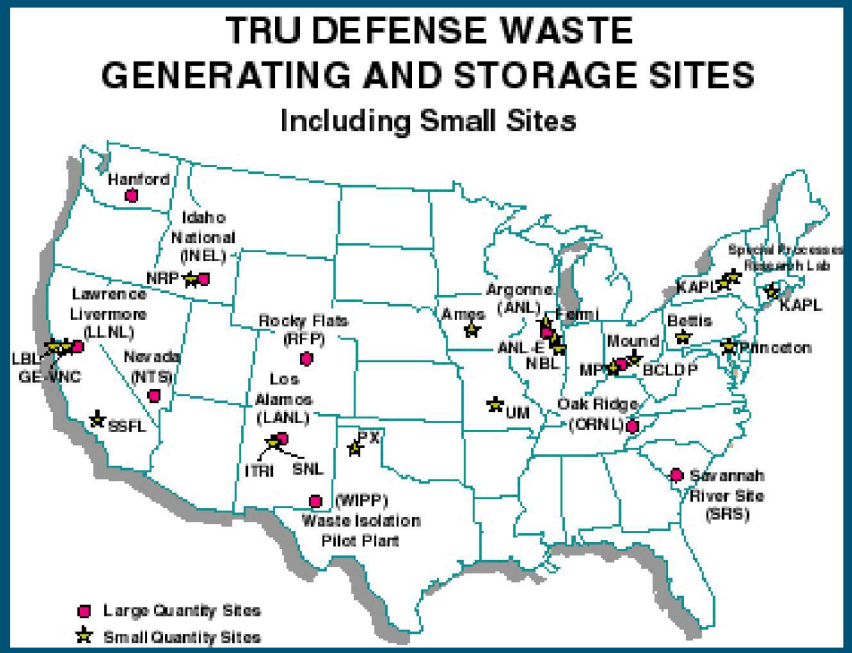
WIPP repository for TRU nuclear waste from defense activities



Operating since 1999; recertified in 2004 & 2009

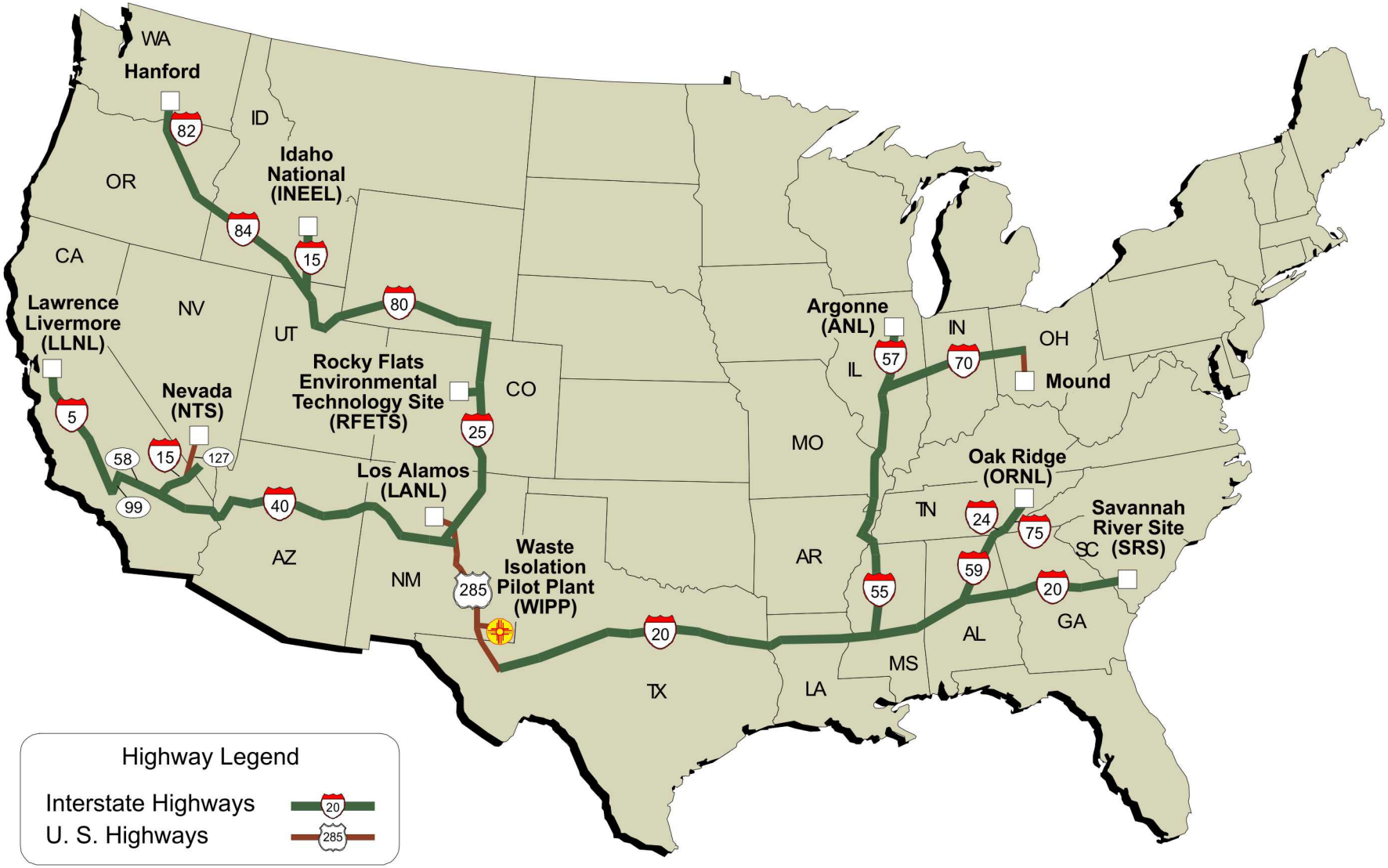
655 m depth in bedded salt

Current Storage Methods Do Not Provide Permanent Solution



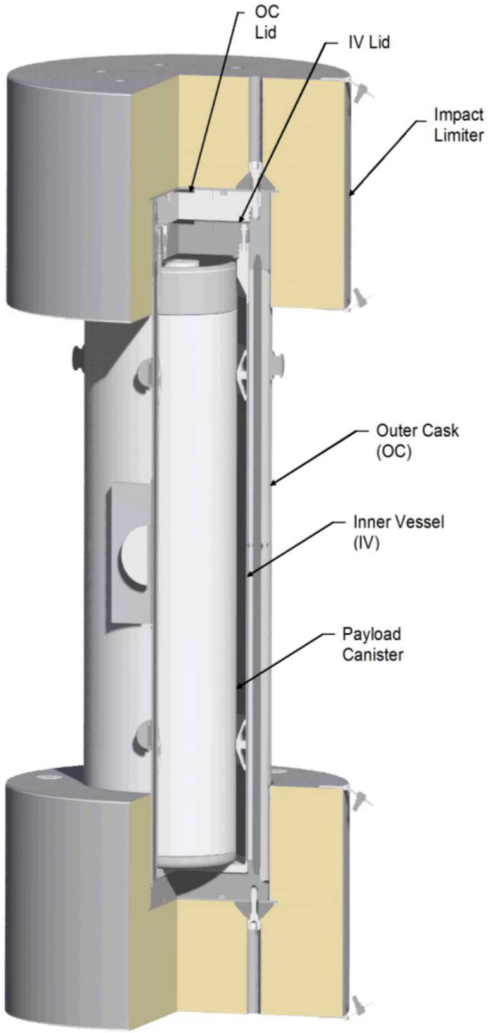
- Waste containers are subject to deterioration and natural disasters
- Long-term radioactivity requires permanent disposal to protect public health and the environment

Defense TRU waste generating and storage sites

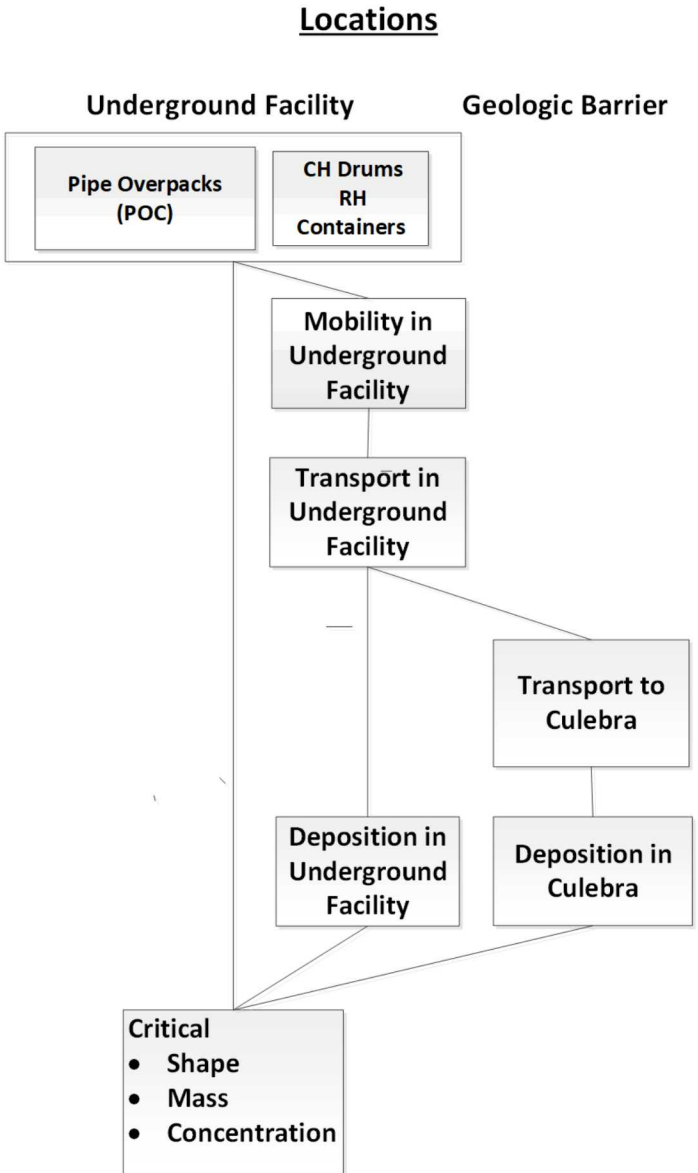


Waste first received in March 1999

RH-TRU 72-B truck cask for shipping remote-handled TRU to WIPP



Pathway to criticality may involve several processes



- *Compaction*
- *Degradation*
- *Dissolution*
- *Colloid Formation*
- *Fluid Flow*
- *Precipitation*
- *Adsorption*
- *Colloidal Aggregation*

Examples of Regulatory Screening Criteria

- **Exclusion of deliberate human disruption**
  - **Excluded FEPs include reentry to recover resources, sabotage, acts of war, archeology, etc.**
- **Exclusion of all disruptive human activities for 100 years after closure**
  - **Active control over the site will prevent disruption**
- **Human intrusion after 100 years must be considered in U.S. regulations**
- **FEPs beyond 10,000 years need not be considered for WIPP**

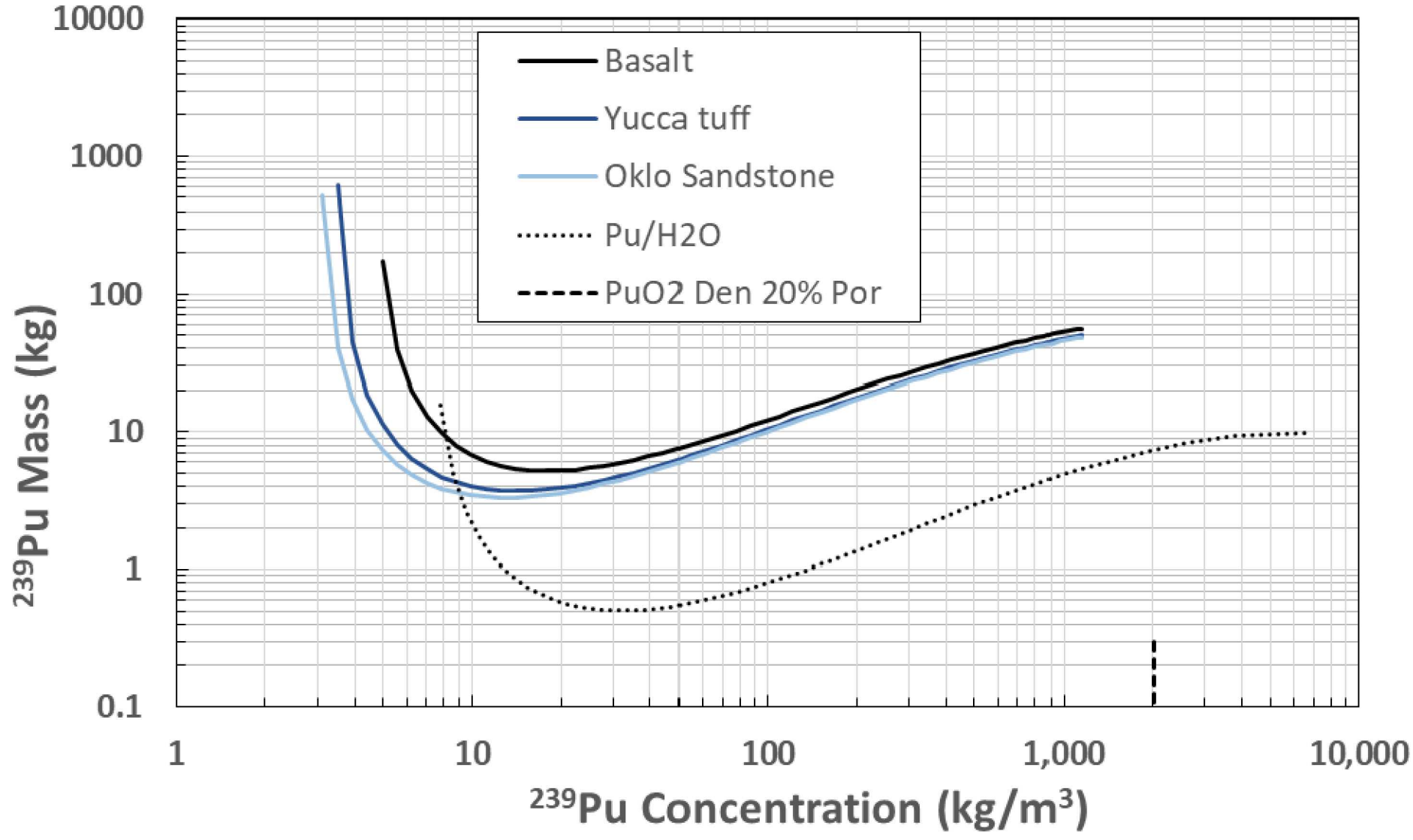
Consequence Criteria

- FEPs can be excluded from the PA if overall system performance is not significantly affected by their occurrence or nonoccurrence
- Consequence-based screening arguments may
  - Evaluate impact on intermediate performance measures
  - Use deterministic and in some cases bounding analyses
  - Use models and codes external to the PA
  - Rely on varying levels of analysis
    - Reasoned arguments based on literature
    - Hand calculations
    - Extensive site characterization or modeling outside of PA
    - PA sensitivity analysis
  - Example
    - Normal processes with little effect, such as erosion

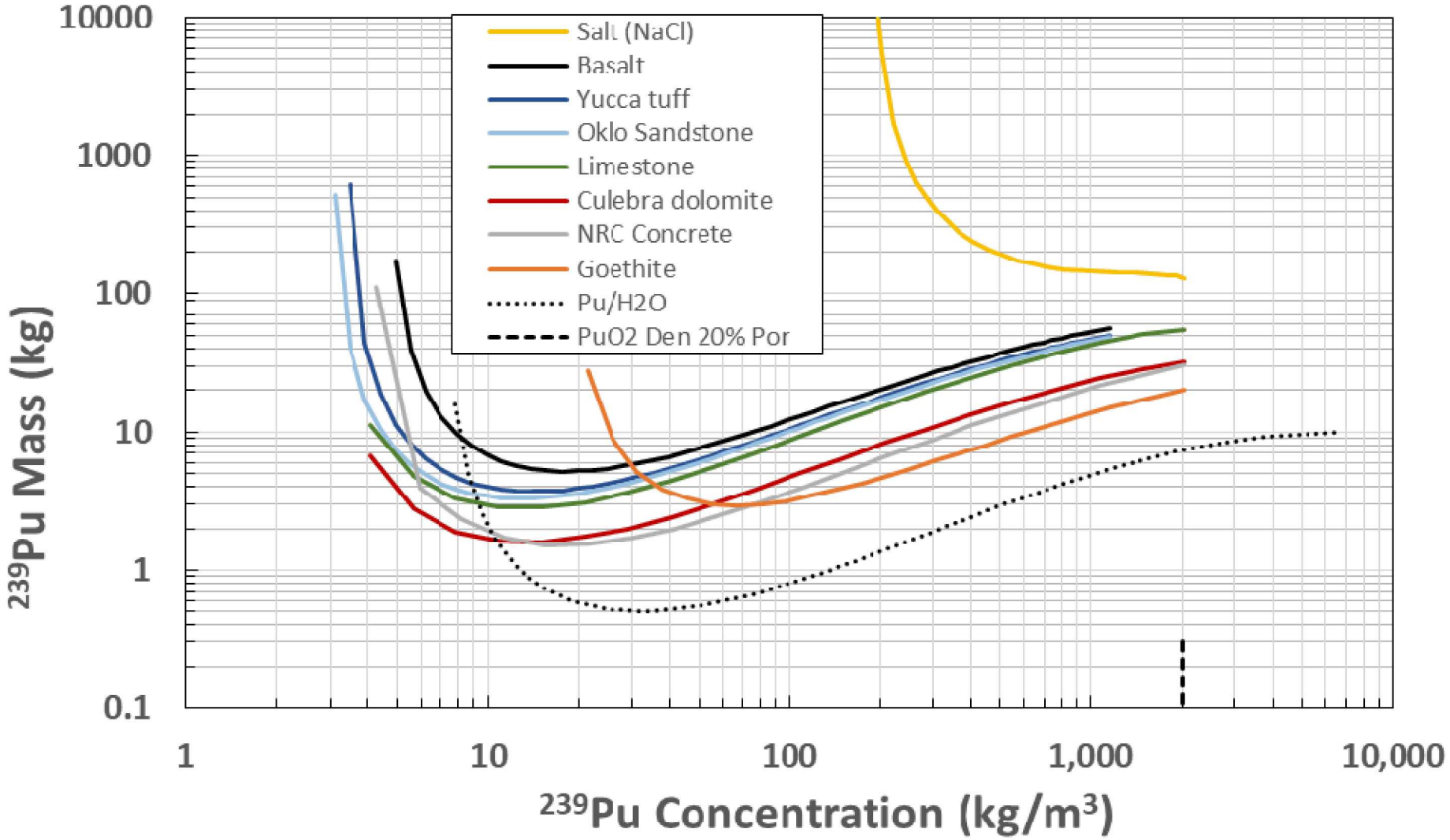
Consequence Criteria (cont.)

- Exclusion of FEPs with beneficial consequences
  - The applicant may choose a conservative analysis that knowingly excludes some FEPs that could only improve overall performance if included
  - Purpose of exclusion may be to
    - Simplify PA calculations
    - Decrease site characterization costs
    - Decrease experimental or design costs
  - Excluded "beneficial" FEPs should have no potentially negative consequences
  - Example
    - Sorption in WIPP shaft seals

Addition of SiO_2-rich media to Pu/H_2O system increases Pu mass but reduces Pu concentration necessary for criticality



Comparison criticality limits in SiO_2, carbonate, and Na-rich media



Heterogeneous model requires less mass at small porosity