Depleted Uranium (DU) Beneficial Use in a Geologic [Yucca Mountain (YM)] Repository System

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Outline

- Introduction
- Uranium disposal
- Repository operations
  - Minimize handling
  - Shielded system
- Repository performance
  - Internal support of waste package (WP)
  - Chemically reducing conditions with pH control
  - Reduced groundwater flow
  - Sorption of radionuclides
  - Uranium isotopic dilution
  - Criticality control
  - Richards Barrier
- Conclusions

Introduction

Approach to Repository Benefits

- **The use of depleted uranium (DU) in a repository requires**
  - **Identification of benefits**
  - **Proof of benefits, with sufficient supporting information to obtain acceptance by the regulator**
  - **Reasonable confidence of no major drawbacks**
  - **Viable economics**
- **This presentation describes each of the benefits that have been identified**
- **The path forward is to provide in-depth understanding of the benefits and costs**

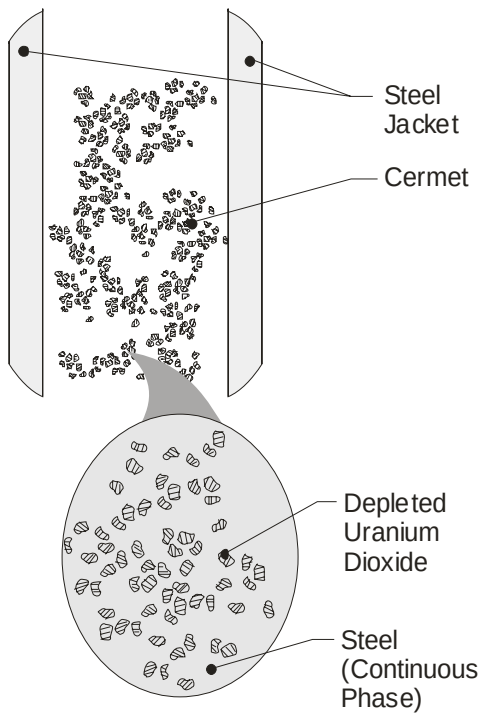
Four Repository Applications for DU

- Cermet multipurpose cask
  - Store spent nuclear fuel (SNF) at reactor
  - Transport SNF to the repository
  - Serve as inner WP at the repository
- Cermet WP
  - Serve as inner WP
  - Use as basket structure
- DUO_2 fill in SNF WP
- DU in Richards barrier

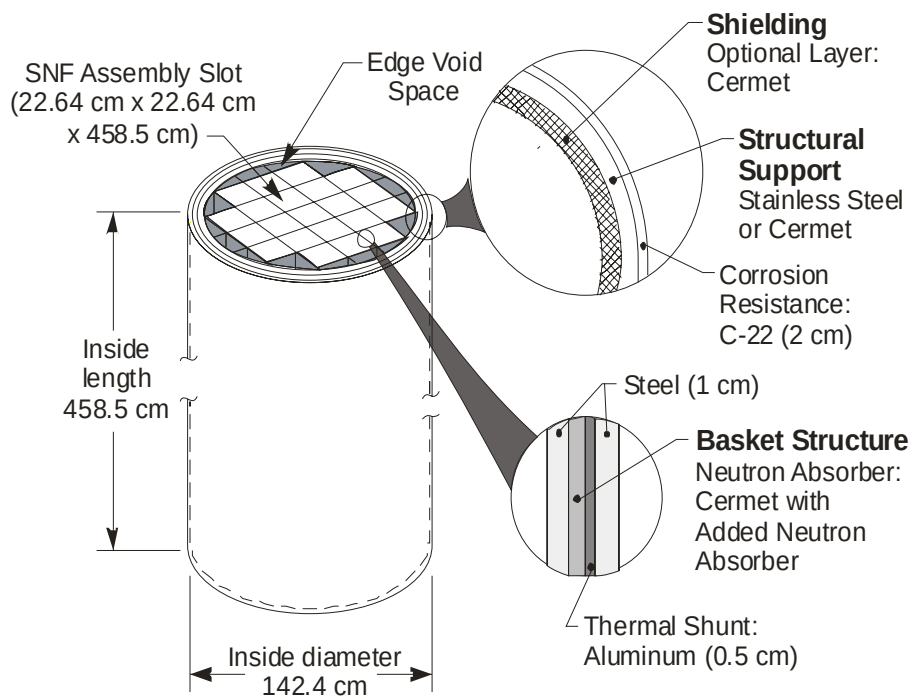
Storage, Transport, and Repository Applications: Casks Can Be Constructed of a DUO_2-Steel Cermet: 3–8 kg DU/kg SNF

(Manufacturing Demonstrated for Small Objects: Cermets Were Used as Fuels in Some Reactors)

Cermet

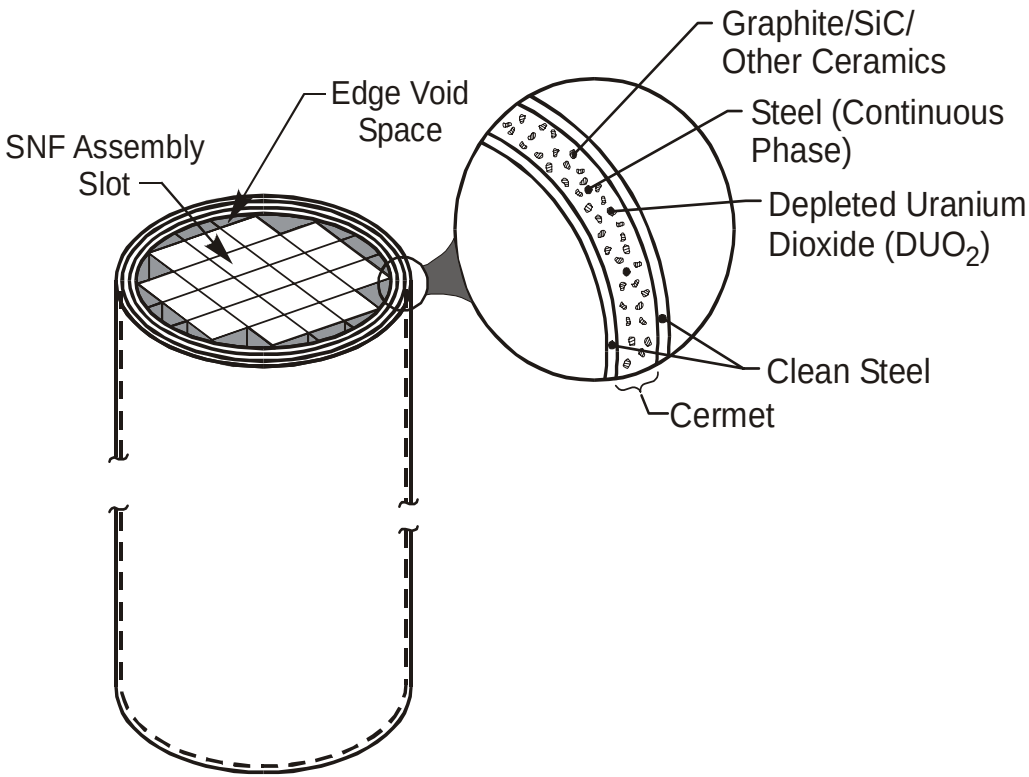


Applications



Cermets Are the Enabling Technology for a Super Cask

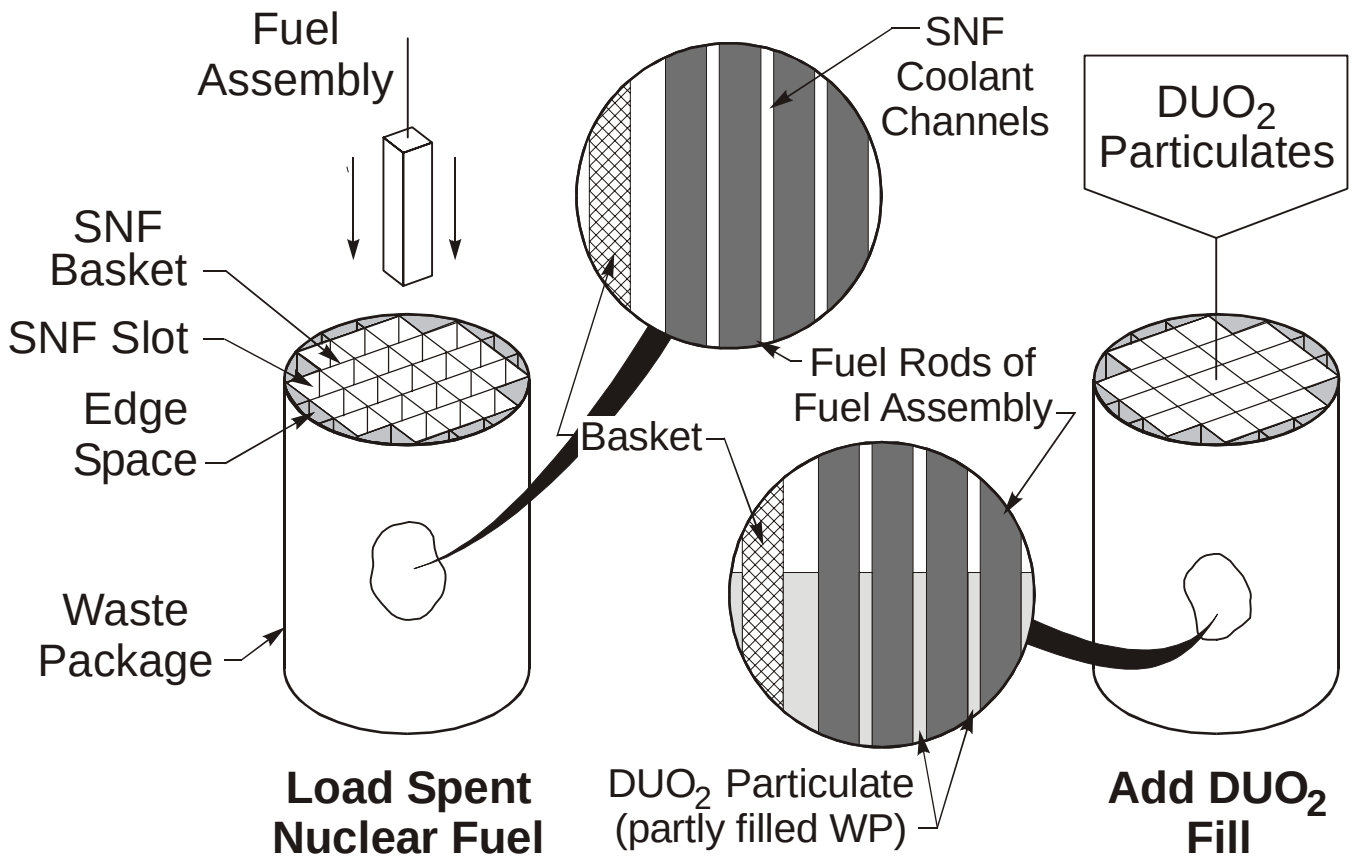
(Ceramics in Metal Matrix to Obtain Advantages of Both)



Functions

- Radiation Shielding
  - Gamma: High-Density DUO_2/Other
  - Neutron Moderation/Absorption
    - Oxygen in DUO_2
    - Carbon in SiC and Graphite
- Assault Protection: Multilayer Cermet (Traditional Armor)
  - Ceramic (Al_2O_3, DUO_2, SiC, Other)
  - Metal
- Safeguards and Theft
  - Large Mass
  - Vault Construction: Multilayer Cermet
- Decay Heat Removal
  - High Conductivity Steel Matrix

DUO_2 Particulate Fill Can Be Added to SNF WPs (3-4 kg DU/kg SNF)



Uranium Disposal

Disposal Requirements for DU Are Uncertain: Repository Disposal Is Acceptable

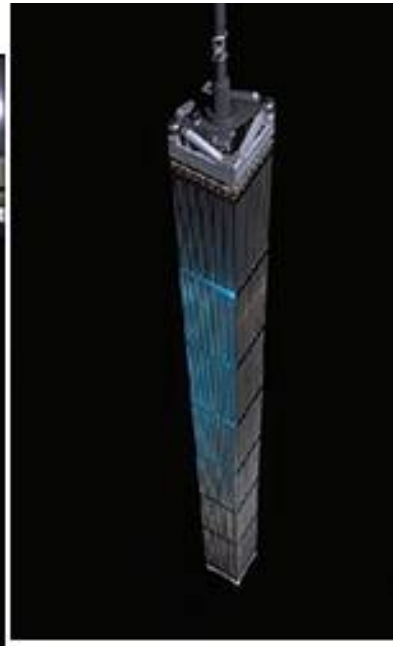
- **Regulatory perspectives**
  - Nuclear Regulatory Commission (NRC): Deep disposal (mine or equivalent) preferred
  - Europe (France and Germany) require geological disposal
- **Yucca Mountain Project (YMP) Evaluation**
  - YMP evaluated DU disposal (various oxide forms)
  - Disposal in separate drifts in steel drums
  - YMP performance assessment indicated no major impacts
- **Commercial perspectives**
  - Liability is a major factor in business decisions
  - End-of-life liability is a major burden for products
  - Repository applications avoid this major commercial barrier

DU Oxides Are the Preferred Forms of DU for the Repository

- Applications must be consistent with NRC policies and positions
  - DU oxides acceptable in repository
  - DU metals questionable, fluorides unacceptable
- Applications must be consistent with repository performance goals
  - Avoid materials defined as unacceptable by YMP: concrete, organics, RCRA materials, etc.
  - Use acceptable materials (ideally, materials that are used in the existing repository design): UO_2, steel
- DUO_2 is the only acceptable oxide for cermet fabrication
  - Cermet fabrication is a high-temperature process
  - Other DU oxides decompose to DUO_2 at high temperatures

Cermet/Fill WPs Enable Corecovery of DU and SNF—If Needed in the Future

(Shielded WPs Simplify Recovery)



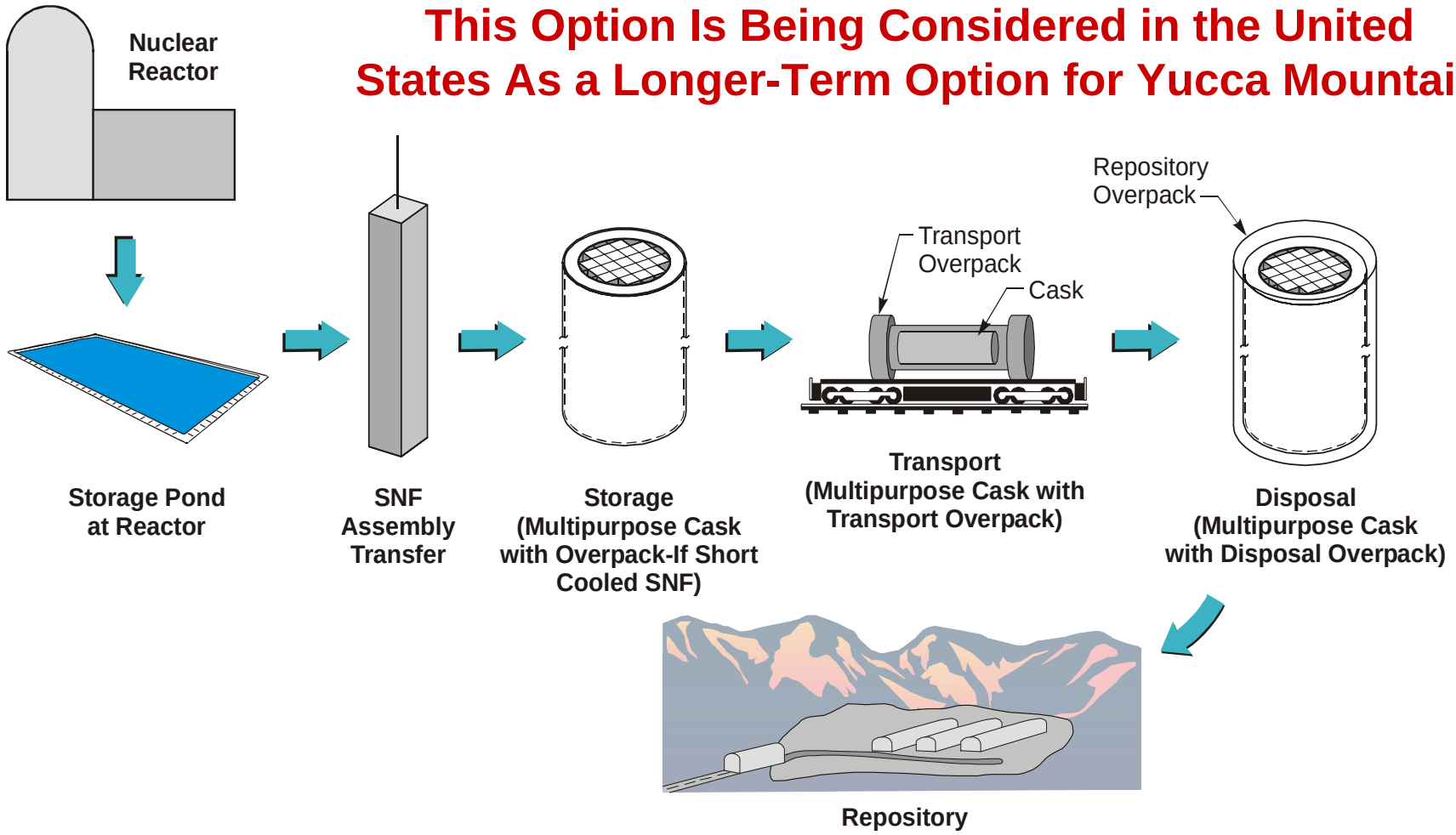
Repository Operations

Minimize Handling

Shielded System

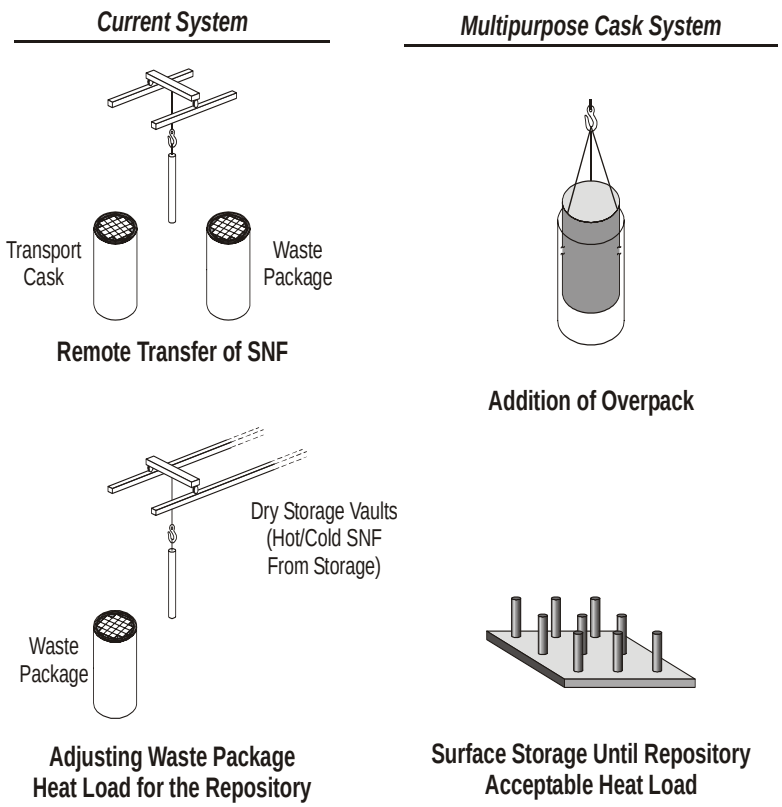
Multipurpose Casks and Canisters May Allow SNF Loading at the Reactor and Disposal at the Repository

This Option Is Being Considered in the United States As a Longer-Term Option for Yucca Mountain



Multipurpose Cask Minimizes Site Operations

(Avoid SNF Transfer Operations from Transport Cask, to Lag Storage, to WP, to Repository)



- Surface operations
  - Multipurpose cask storage replaces SNF sorting to meet WP heat limits
  - Contact-handled WP surface operations
    - Add overpack
    - Add fill (optional)
- Underground waste package operations
  - Contact handled
  - Easy retrieval
  - Heavy packages (100 t)
- Separate DU disposal facility is not required

Repository Performance

Internal Support of WP

Chemically Reducing Conditions with pH Control

Reducing Groundwater Flow

Sorption of radionuclides

Uranium Isotopic Dilution

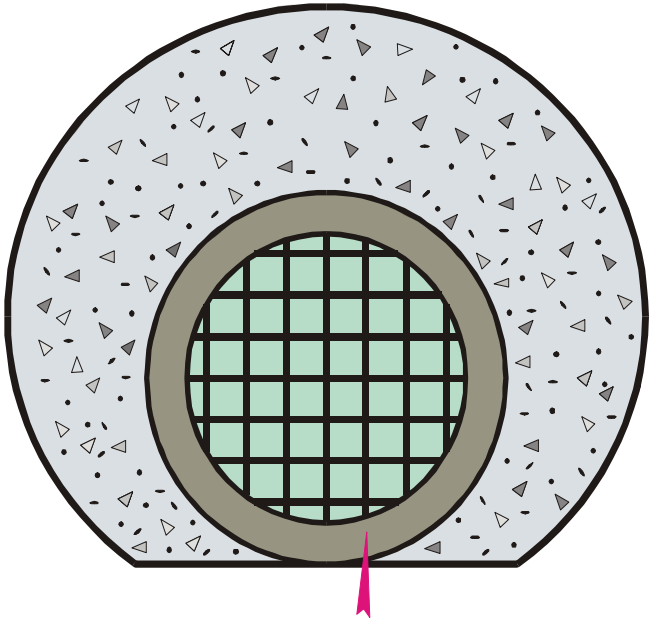
Criticality Control

Richards Barrier

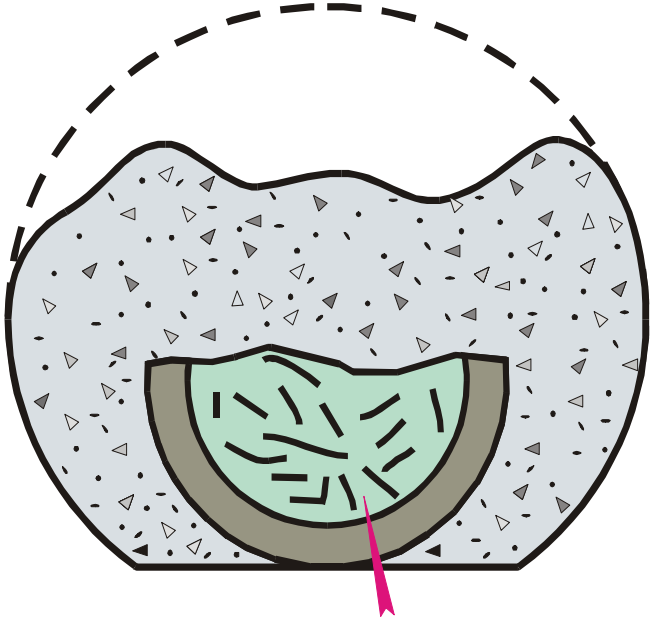
Repository Performance

Internal Support of WP

Package Fill Prevents Early Collapse of WP by Providing Internal Support



Intact Waste Package
or Waste Package with Fill
(High Resistance to Collapse)



Failed Waste Package
(Collapse With No
Internal Support)

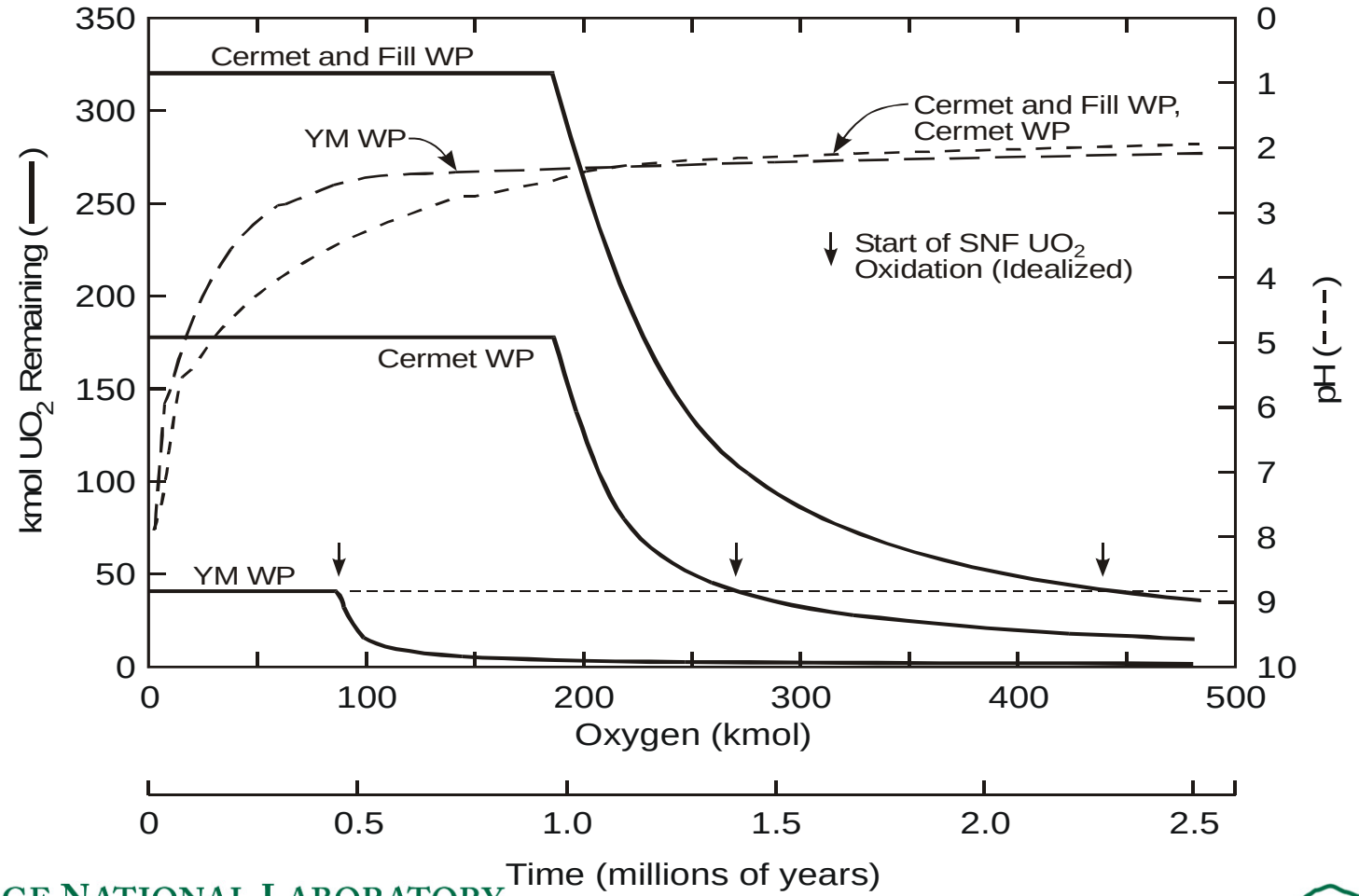
Repository Performance

Chemically Reducing Conditions with pH Control to Slow SNF Dissolution

Observations

- The YM Repository has an oxidizing geochemical environment
- Most radionuclides are trapped in the SNF UO_2
- SNF degradation is very slow in reducing environments, fast in oxidizing environments
- Fill and cermet WPs contain large quantities of reducing agents [DU dioxide (DUO_2) and iron (Fe)]
- The potential exists to create local zones of reducing agents around the SNF to delay SNF degradation and radionuclide releases

DUO_2 as Sacrificial Cermet or Fill Preferentially Delays Oxidation of SNF by Consumption of Oxygen in Groundwater (Idealized Case) and Controls pH

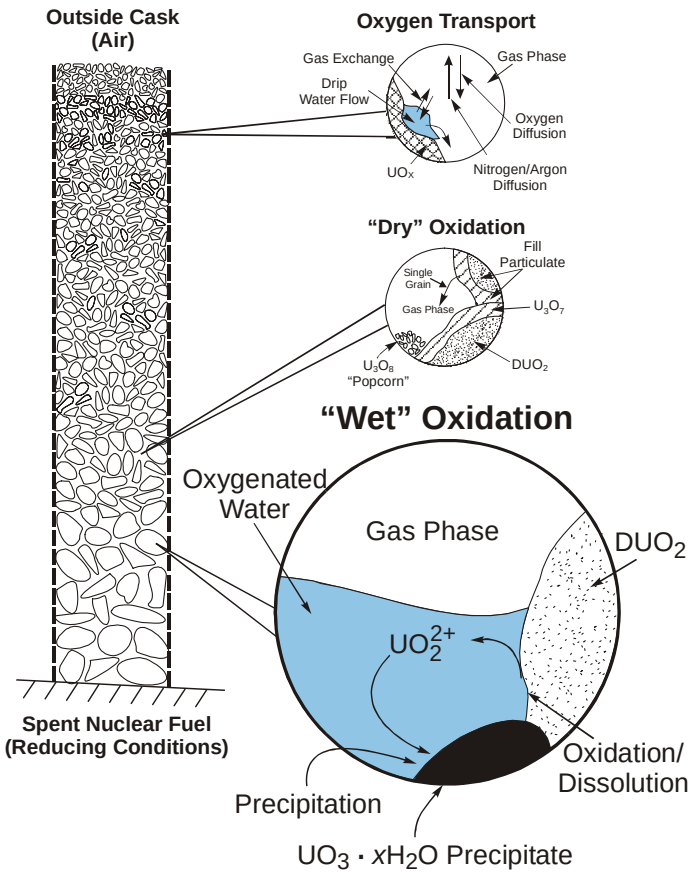


Repository Performance

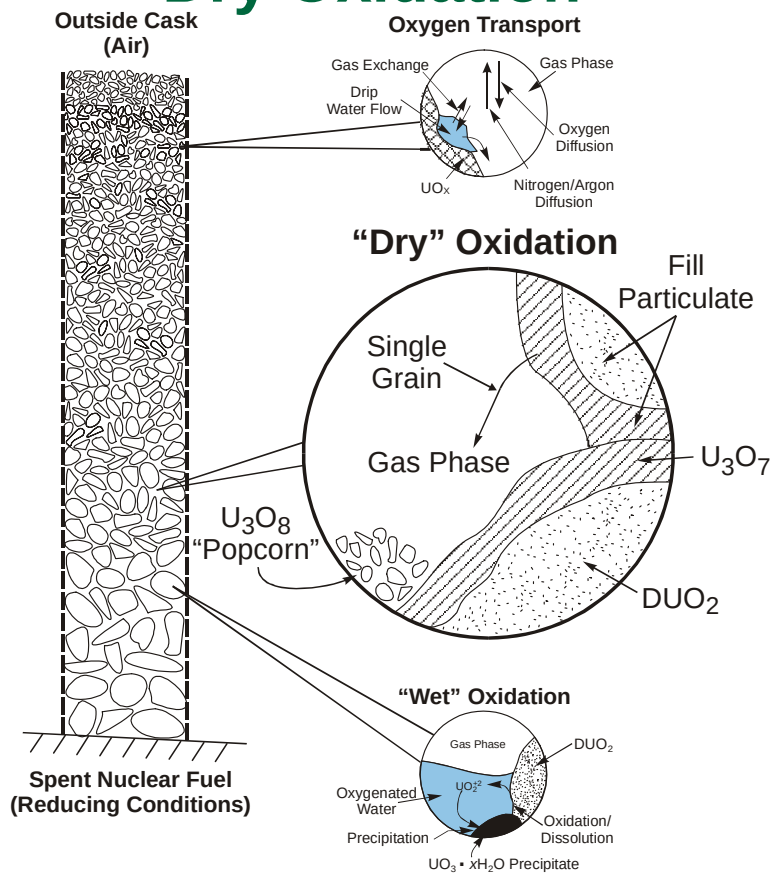
Reducing Groundwater Flow

DUO_2 Oxidation May Slow Groundwater Flow Through Failed SNF WPs by Blocking Water Flow

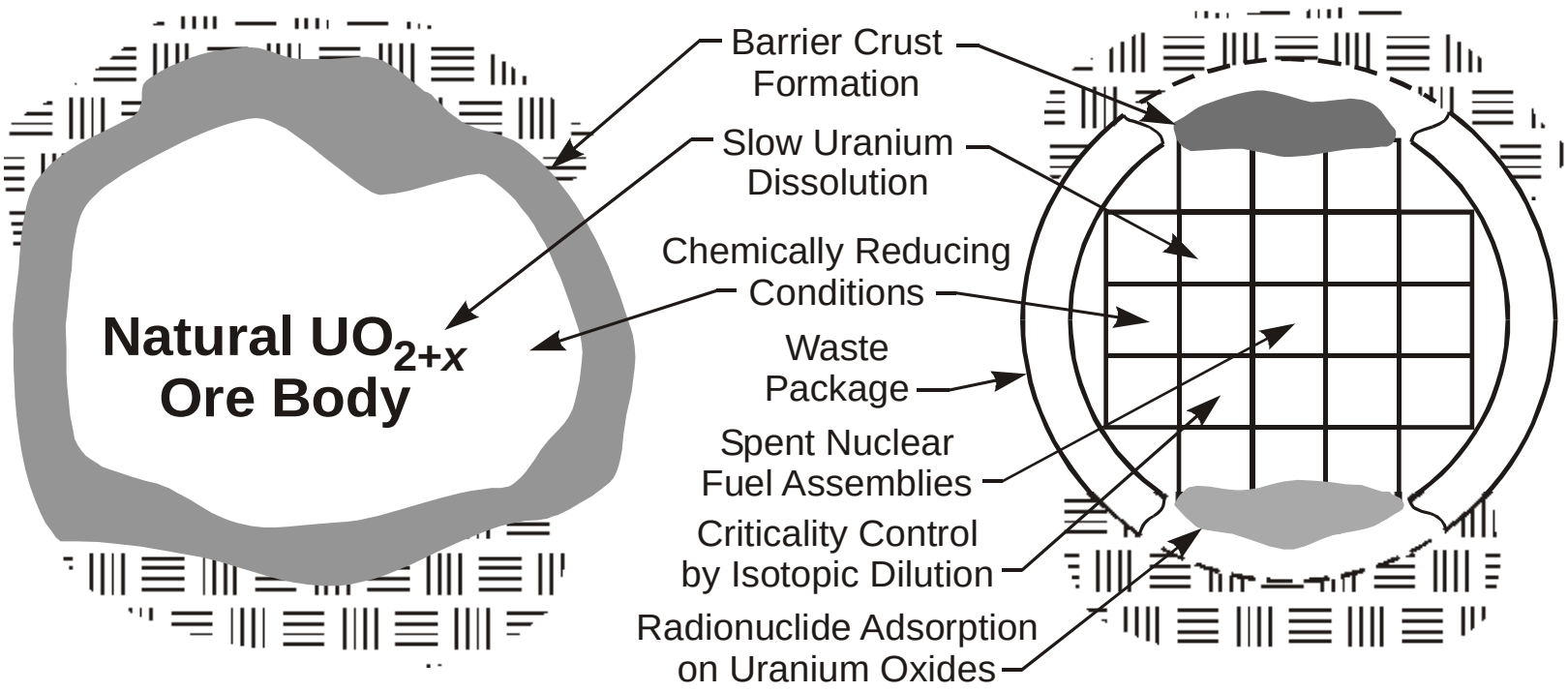
Wet Oxidation



Dry Oxidation



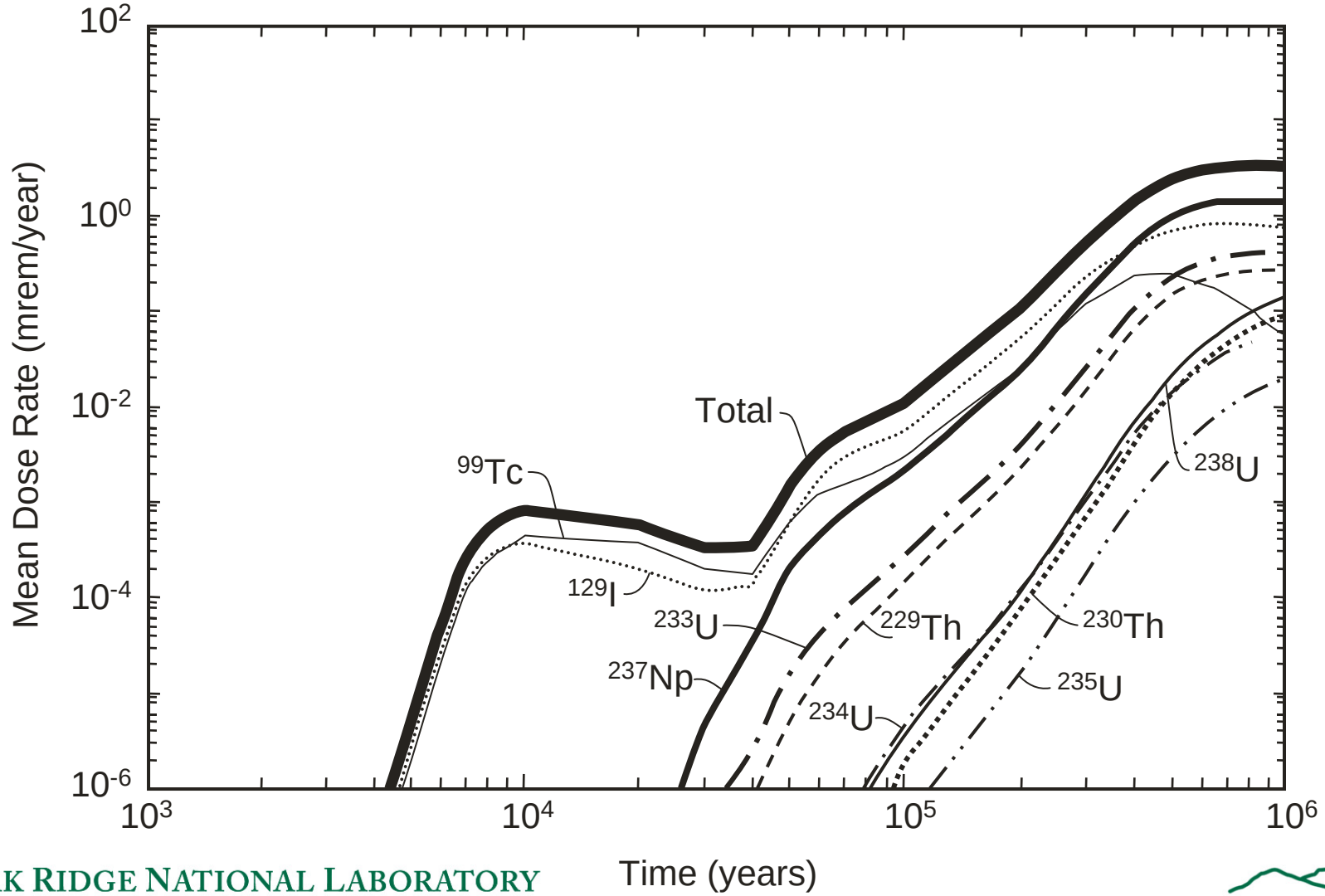
Experience with Natural Uranium Ore Deposits Indicates UO_2 Has Remained Intact for Millions of Years: The Same Mechanisms Should Delay SNF Degradation in Failed WPs Containing DUO_2



Repository Performance

Sorption of Radionuclides

Neptunium Controls Long-Term Radiation Doses from the Repository



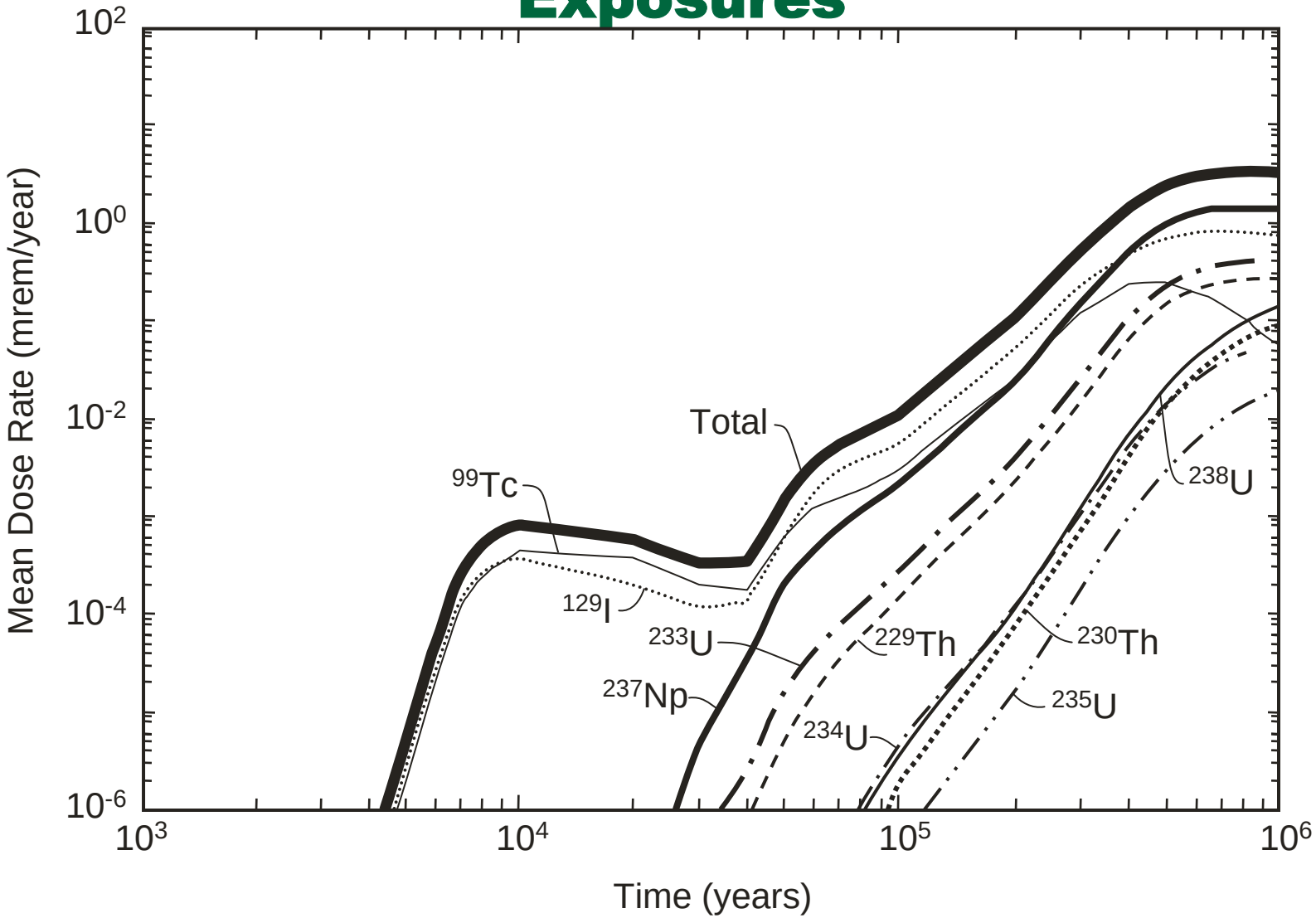
Excess Uranium May Delay Neptunium Releases (Work in Progress)

- ANL data suggest sorption of neptunium on various hydrated uranium oxides
  - ANL studying SNF degradation
  - Need data for neptunium in groundwater flowing through hydrated uranium oxides
- U.S.-Russian program has been initiated to experimentally investigate effect

Repository Performance

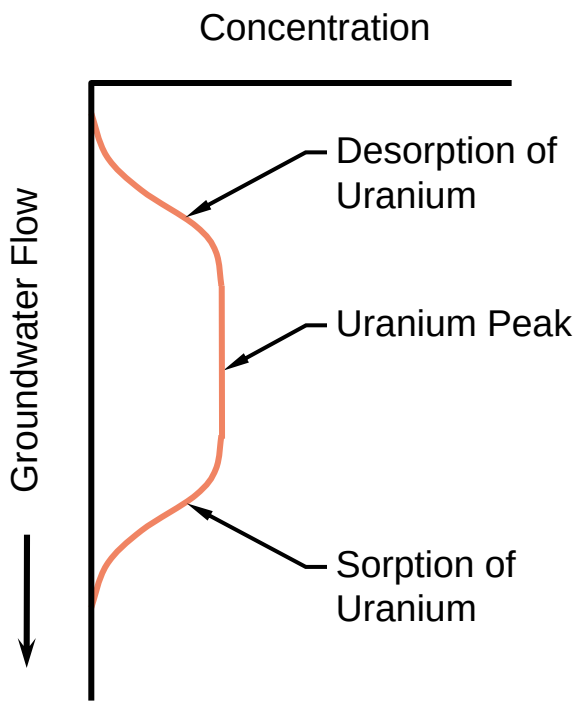
Isotopic Dilution of Short-Lived Uranium Isotopes

Shorter-Lived Uranium Isotopes and Decay Products Contribute to the Expected YM Exposures



DU Addition May Reduce Radionuclide Dose from Other Uranium Isotopes

Groundwater Flow Mixes Isotopes

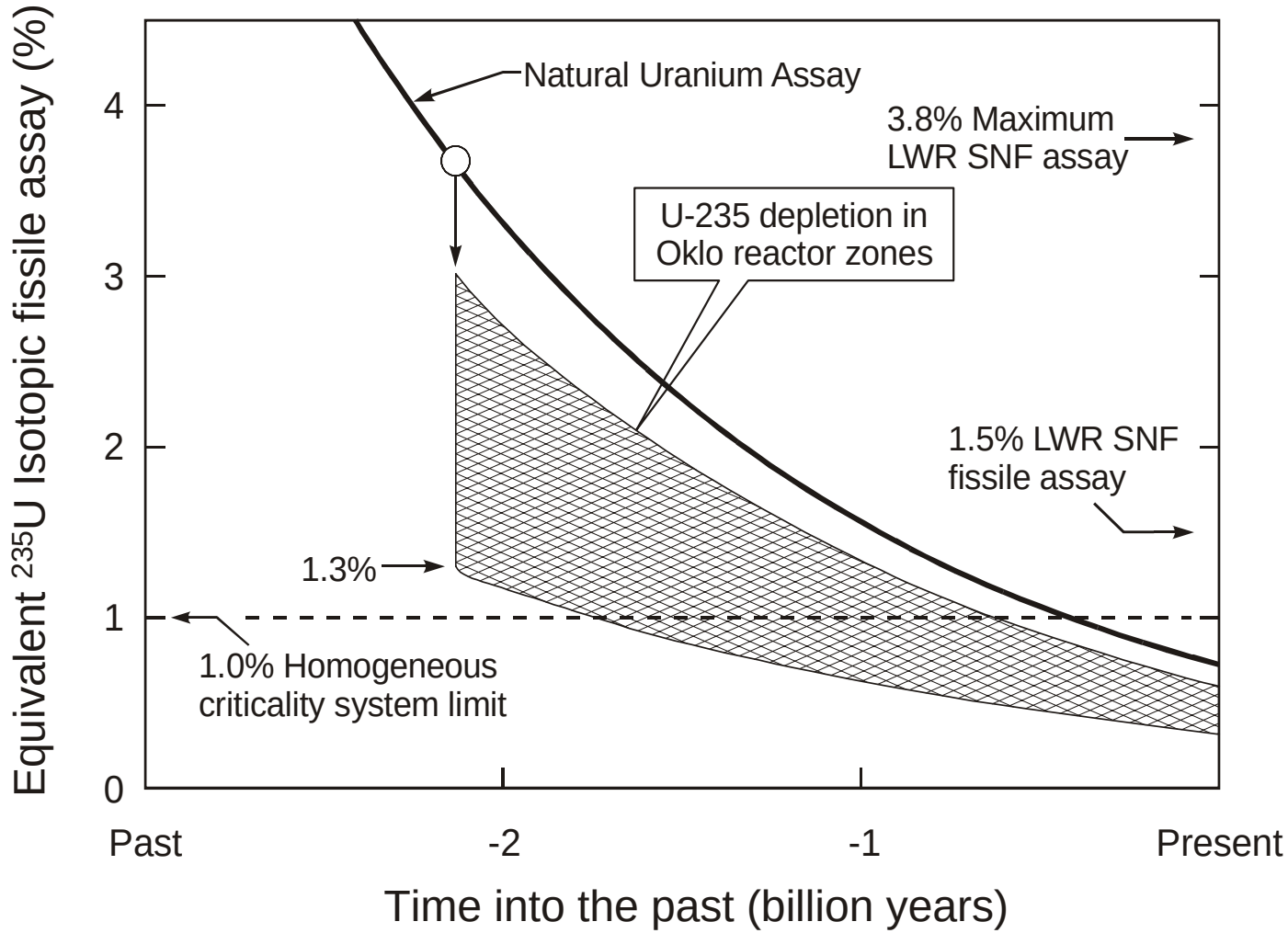


- **Uranium releases**
  - **Controlled by solubility**
  - **Uranium uptake by humans is fixed (for any scenario)**
- **Addition of DU**
  - **Changes uranium isotopics**
  - **Reduces dose from uranium isotopes by dilution with long-lived (low activity) ^{238}U**
    - **^{233}U: $T_{1/2}$ = 160,000 y**
    - **^{234}U: $T_{1/2}$ = 250,000 y**
    - **^{235}U: $T_{1/2}$ = 700,000,000 y**
    - **^{236}U: $T_{1/2}$ = 24,000,000 y**

Repository Performance

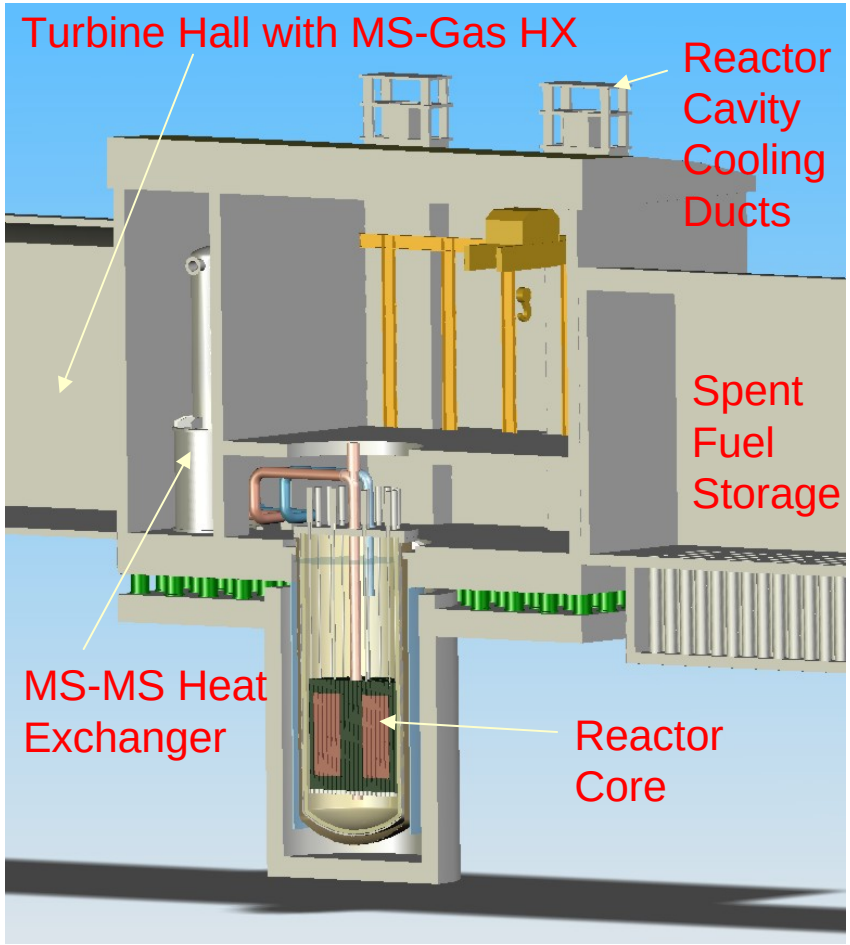
Criticality Control

Criticality: Nature Has Created Nuclear Reactors when the Fissile Assay Exceeds 1.3 wt % ^{235}U Equivalent



Generation IV Very High-Temperature Reactors Will Have Fuel Enrichments of 10-20% ^{235}U

Advanced High-Temperature Reactor

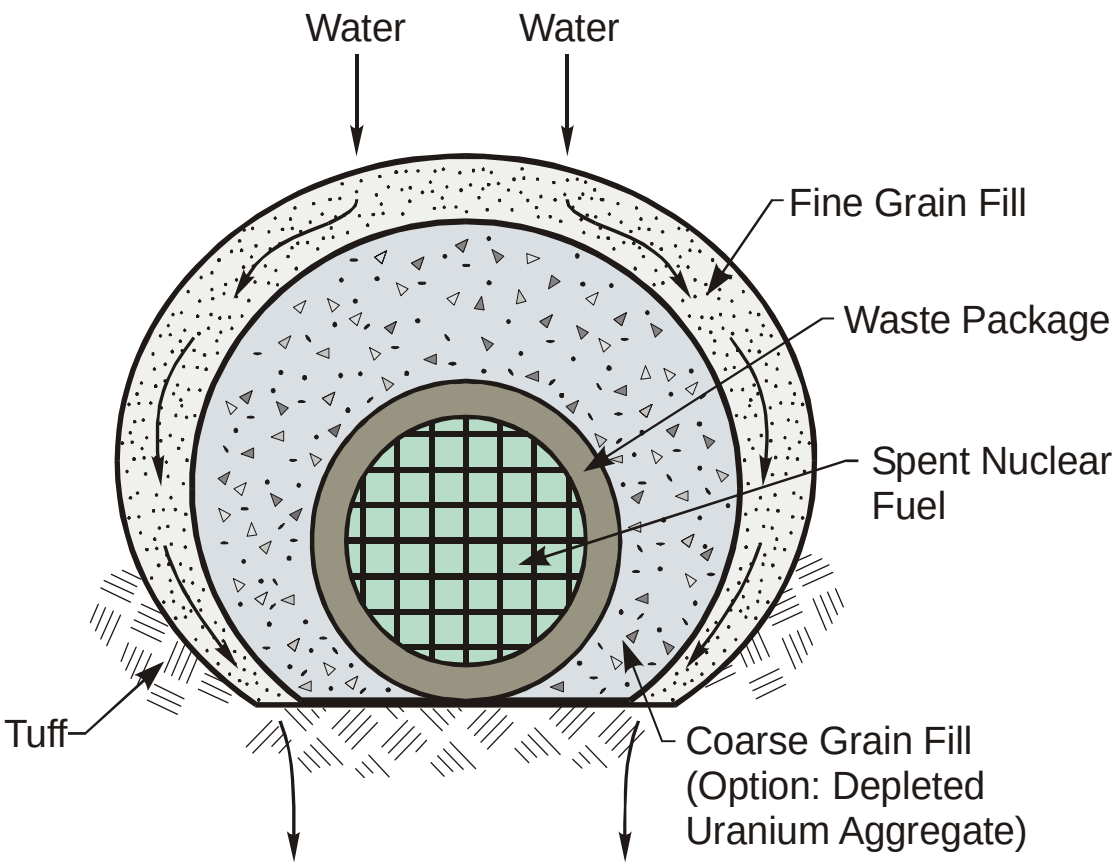


- Generation IV reactors will be designed for electricity and hydrogen production
- DOE priority
- SNF enrichments approach 3% ^{235}U
- Potential for long-term repository criticality events similar to natural reactors in the past
- DU in repository enables isotopic dilution of enriched uranium to avoid criticality

Repository Performance

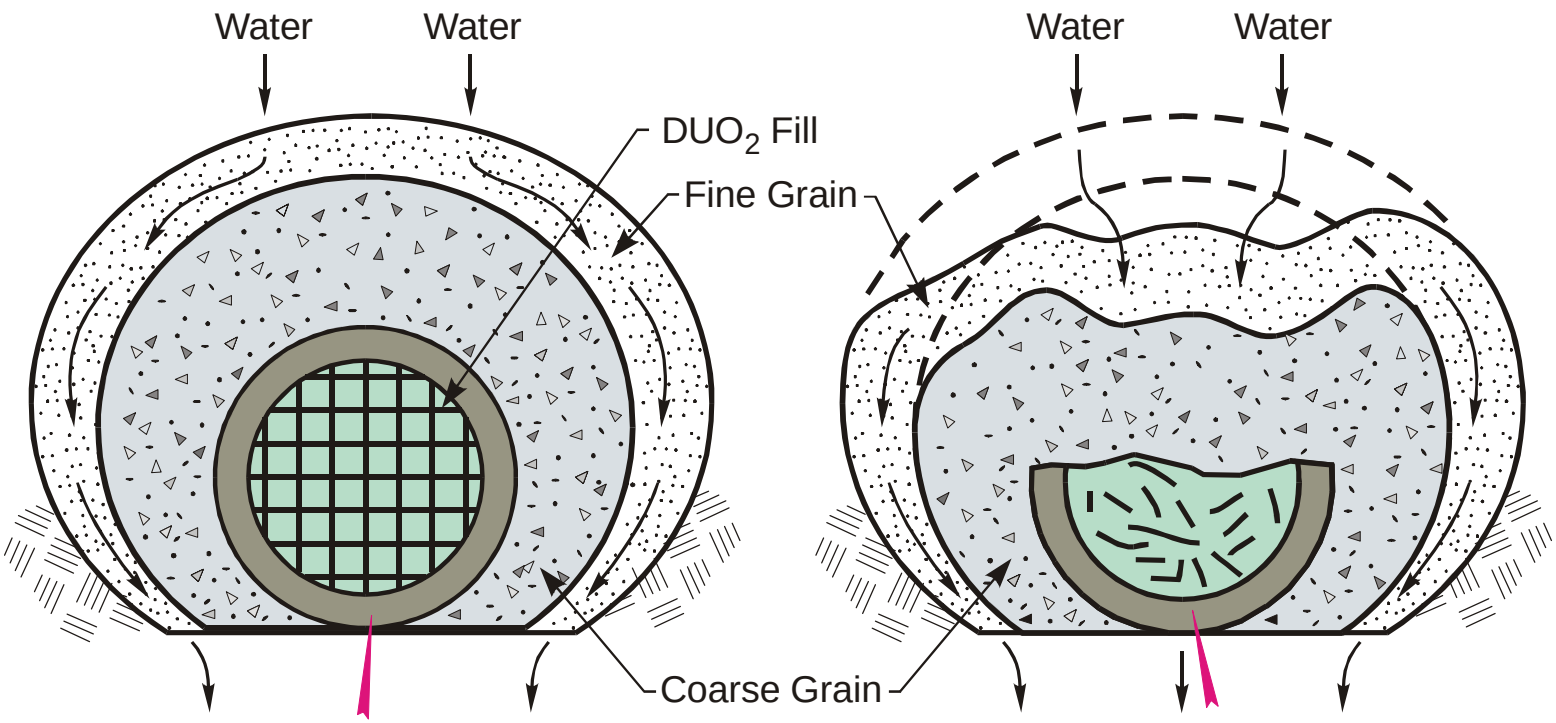
Richards Barrier

Water Can Be Diverted from the WP with a Richards Barrier



- **Barrier diverts water around the WP**
- **DU aggregate in coarse fill**
- **DU not exposed to water until Richards barrier failure**
- **DU exposed to oxidizing air**
- **Potential benefits**
  - **DU disposal**
  - **Local chemical control**
  - **Criticality**

Use of DUO_2 Fill Inside the WP May Extend Richard's Barrier Lifetime



Intact Waste Package or Waste Package with Fill (High Resistance to Collapse)

Failed Waste Package (Collapse With No Internal Support)

CONCLUSIONS

- DU has potentially major benefits to the repository
- The use of DU in a repository requires
  - Reasonable confidence of no major drawbacks
  - Proof of benefits with sufficient supporting information to obtain acceptance by the regulators
  - Viable economics
- The path forward is to develop the case for repository use of DU