Repository Criticality Control with Depleted-Uranium-Dioxide Cermet Waste Packages

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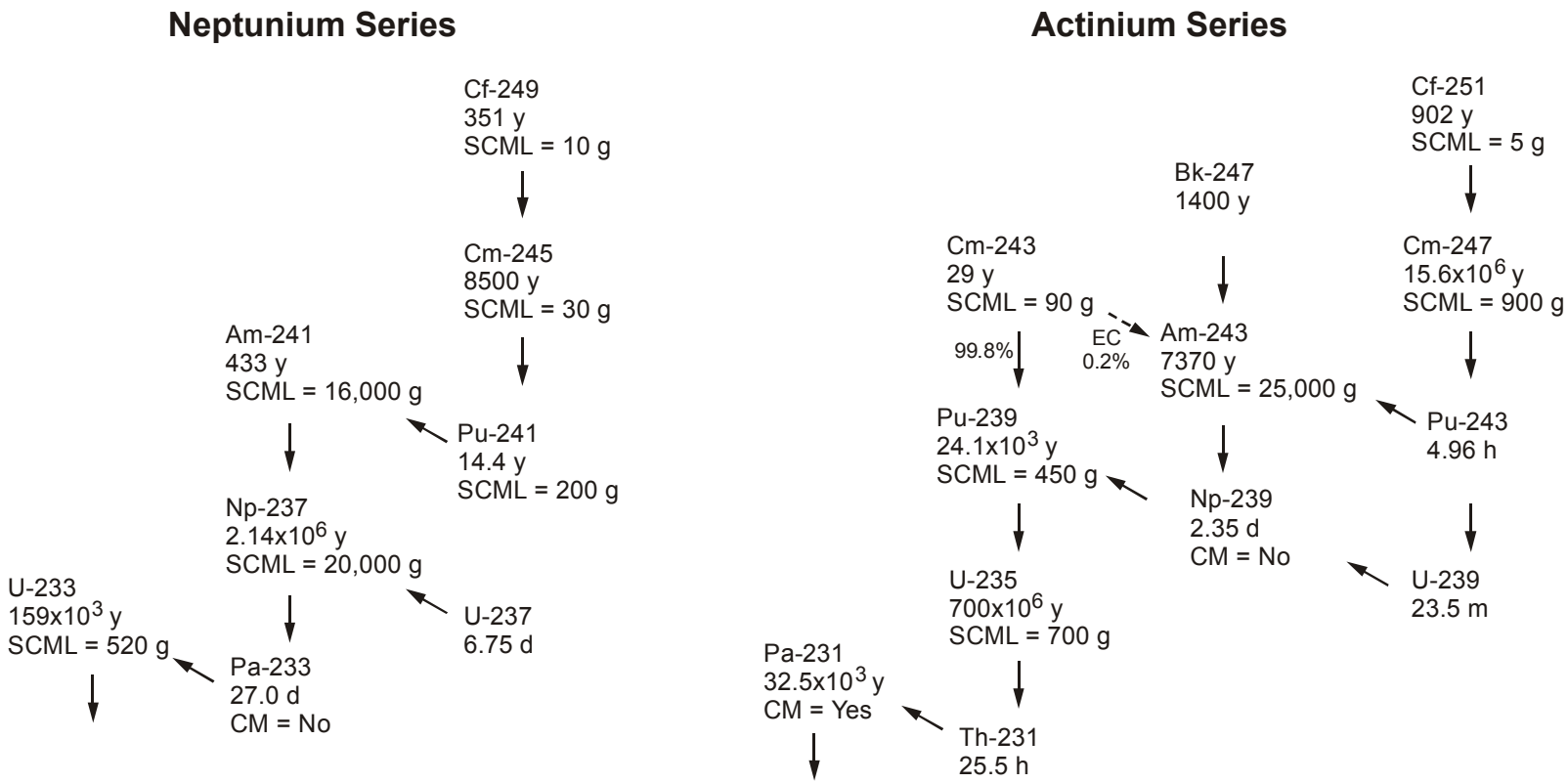
Outline

- Characteristics of Repository Criticality Control
- Cermet Waste Packages
- Cermet Criticality Control Strategy
- Conclusions

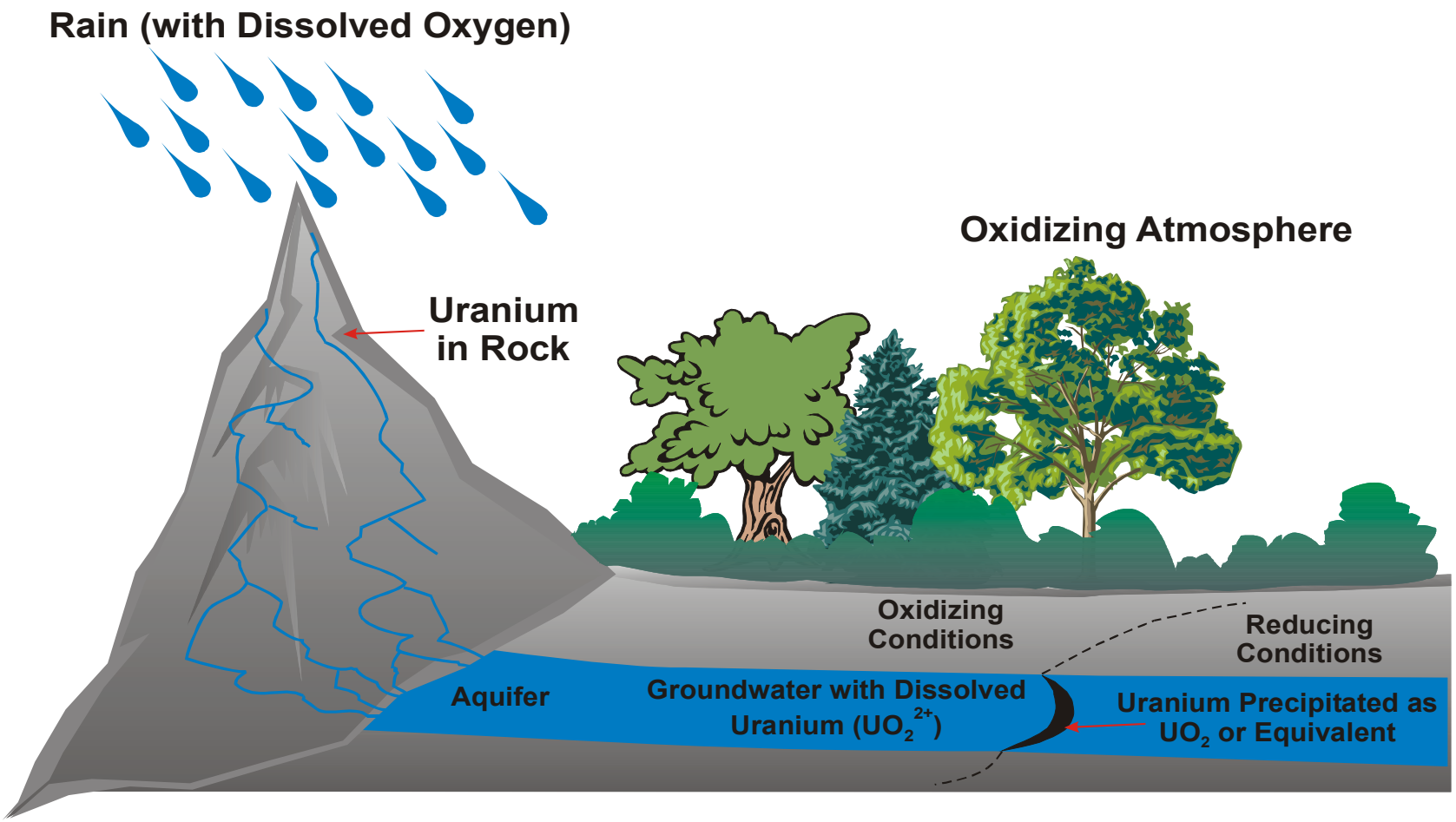
Characteristics of Repository Criticality Control

Actinide Half-Lives and Geochemistry Imply That Repository Criticality Is Controlled by ^{233}U and ^{235}U

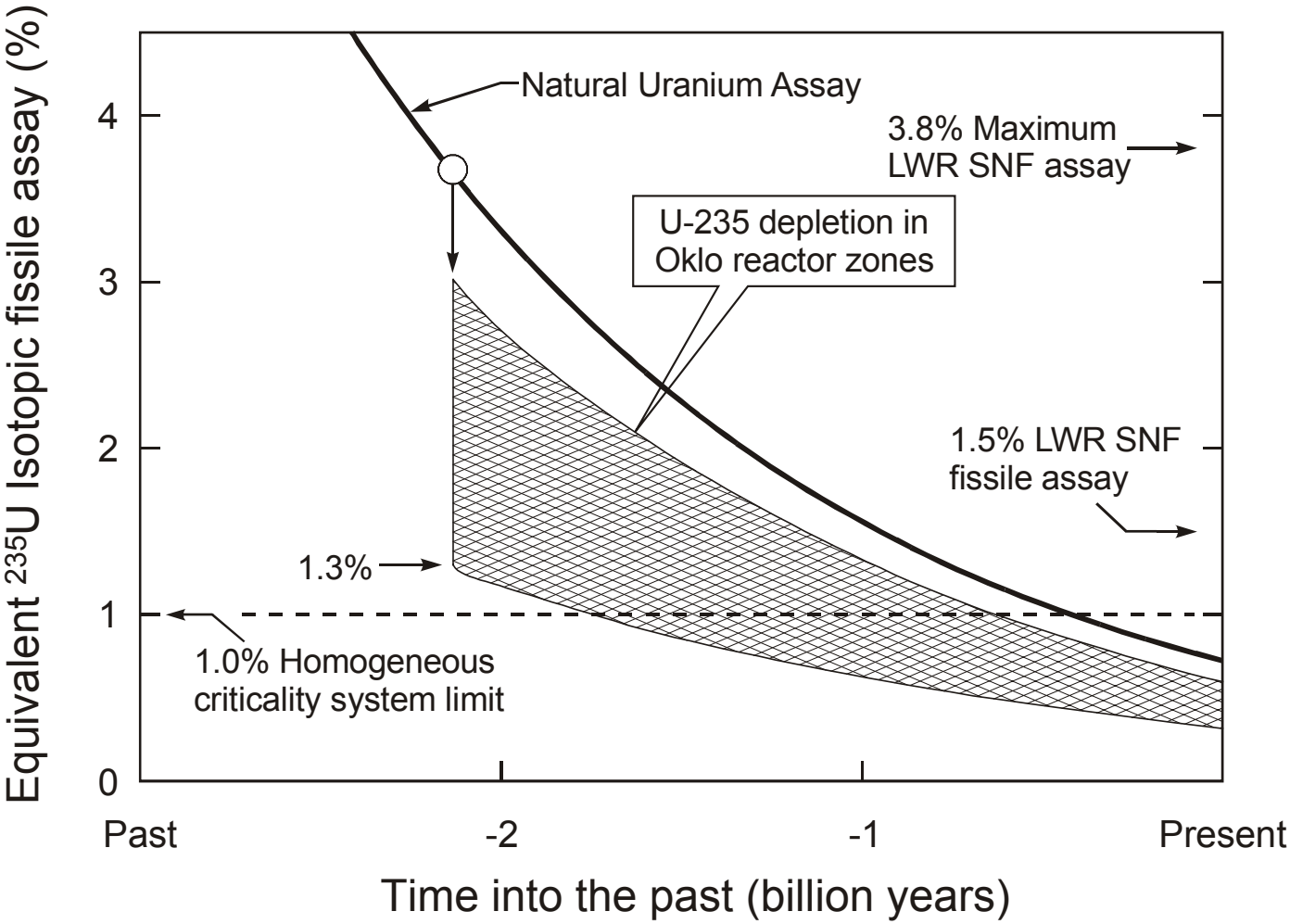
(Major Actinides [^{239}Pu, etc.] Decay to Uranium Fissile Isotopes)



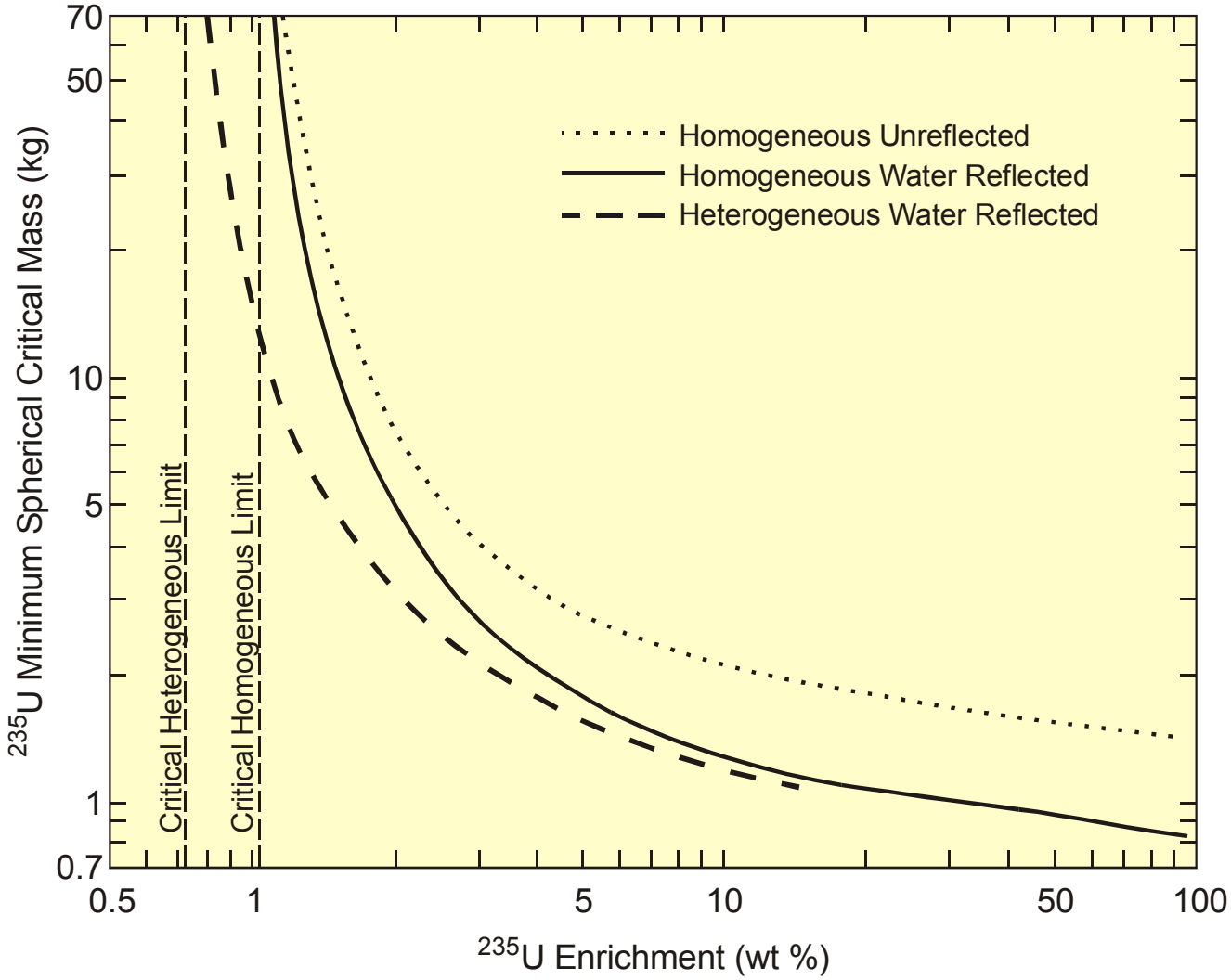
Uranium Geochemistry Destroys and Reconstitutes Natural and Repository Uranium "Ore" Deposits Over Time



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



Nuclear Criticality Can Occur with Enrichments Near 1 wt% in Engineered Systems

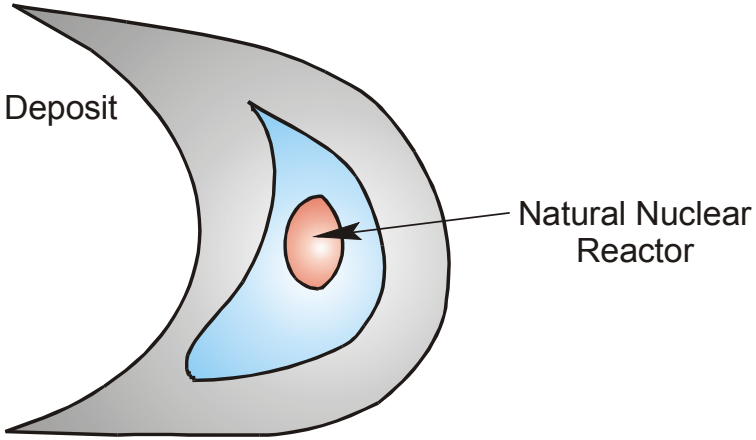


Criticality Is Possible in a Geological Repository

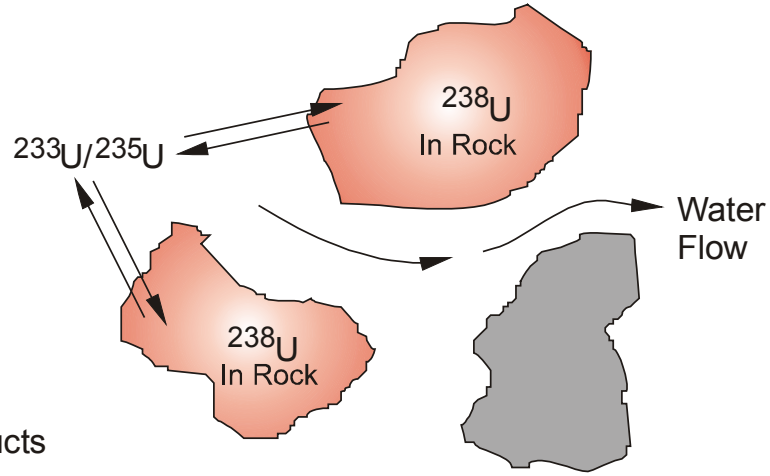
- LWR SNF assay is ~1.5 wt% ^{235}U in ^{238}U (equivalent assay)
- Higher actinides in HLW decay to $^{233}U/^{235}U$ with an ultimate assay that is significantly higher than that of LWR SNF
- Navy SNF and some DOE SNF contain high-enriched uranium

Only Three Means Exist To Eliminate the Potential for Nuclear Criticality

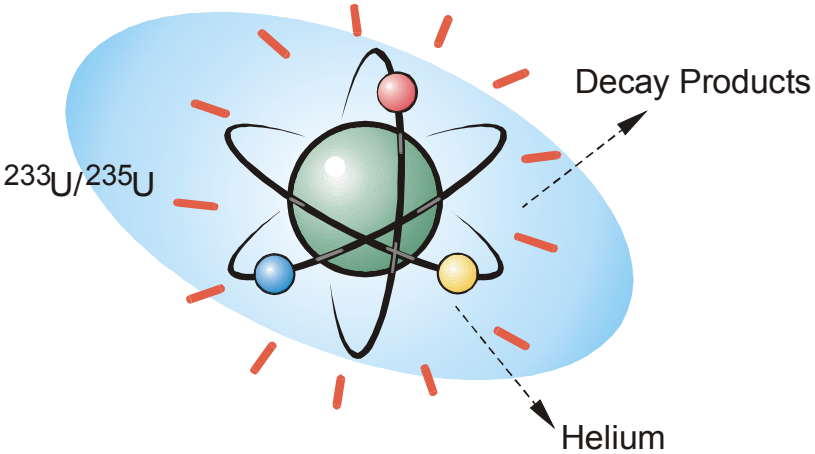
Fission



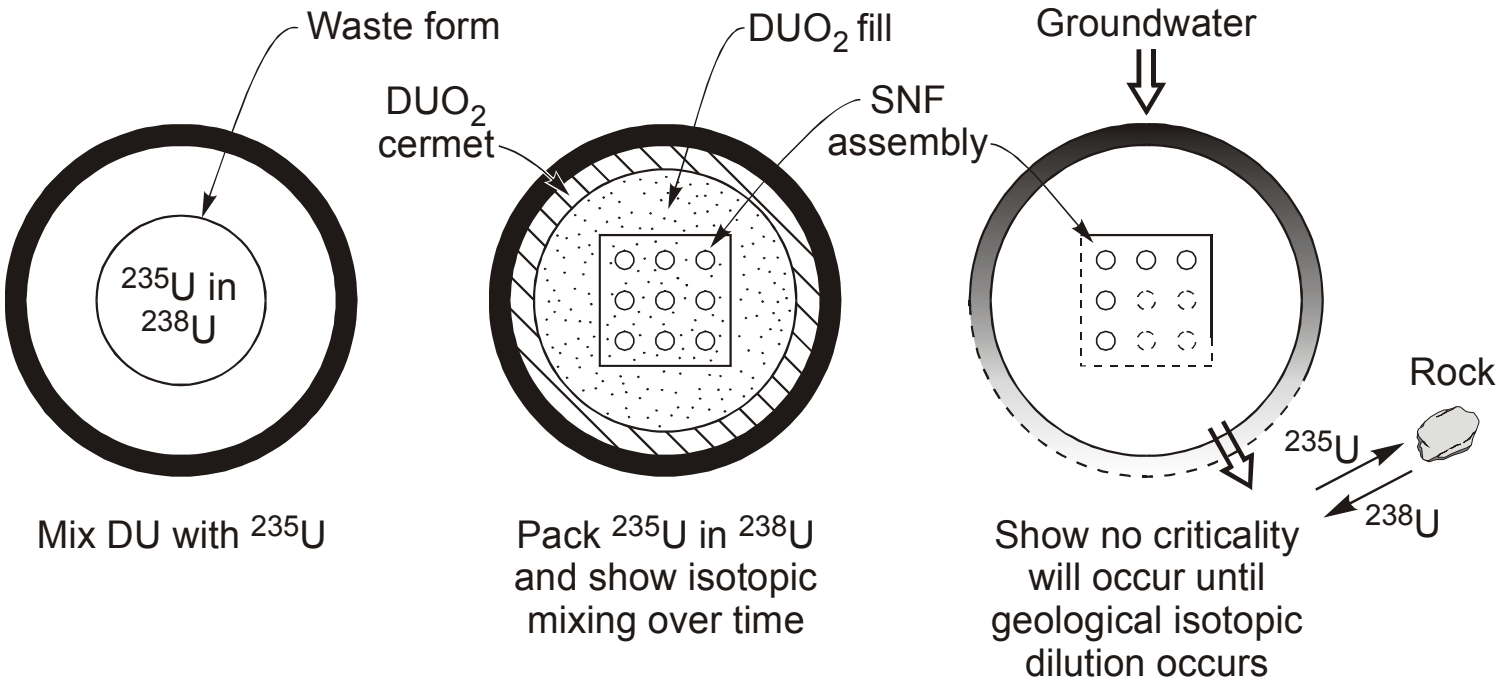
Isotopic Dilution with Natural Uranium in Rock



Radioactive Decay



Three Methods Exist To Ensure That Nuclear Criticality Will Not Occur in a Repository



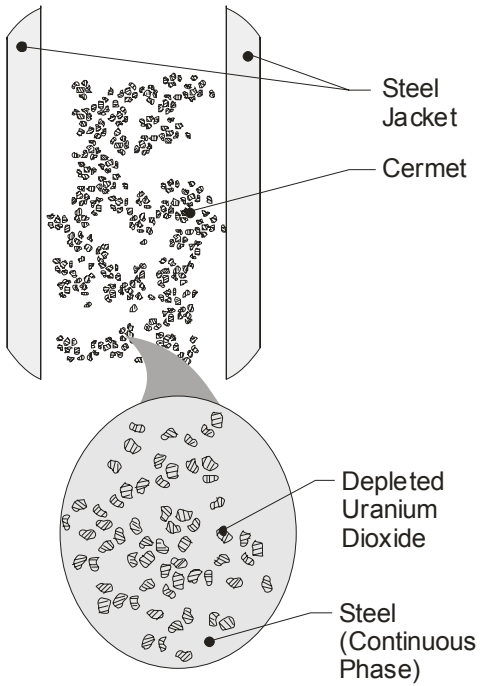
Adding Depleted Uranium (DU) To the Waste Package Has Major Advantages As a Criticality Control Strategy

- Avoids the need to process waste (Option I)
- Minimizes required knowledge of future migration of fissile materials from the waste package (Option III)
- Excess DU (a potential waste) is available
- The strategy uses the same strategy that prevents nuclear criticality in natural uranium ore bodies

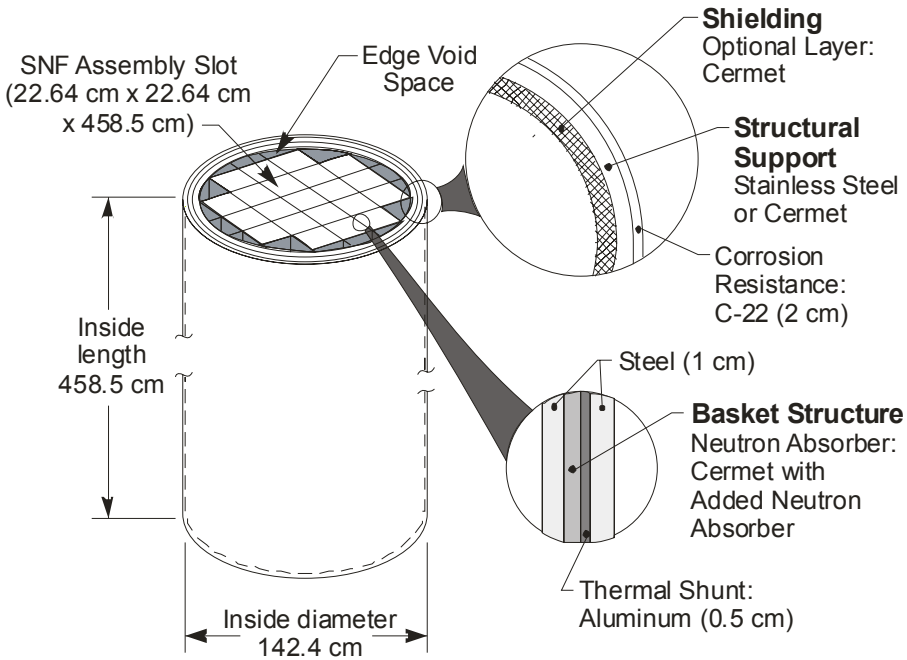
Cermet Waste Packages

Characteristics and Uses of Cermets in Waste Packages for PWR SNF

Cermet



Applications



DUO_2-Steel Cermets Are a Preferred Form of Uranium in a Repository

- The repository is primarily designed to accept SNF uranium in the form of UO_2
  - No chemical compatibility issues with DUO_2
  - Massive knowledge base on behavior of UO_2 in the repository environment
- Cermets minimize operational issues
  - No exposed uranium
  - Same metals of construction
- Significant cermet experience
  - Eleven reactors operated on cermet fuels
  - High-volume production of non-nuclear cermets

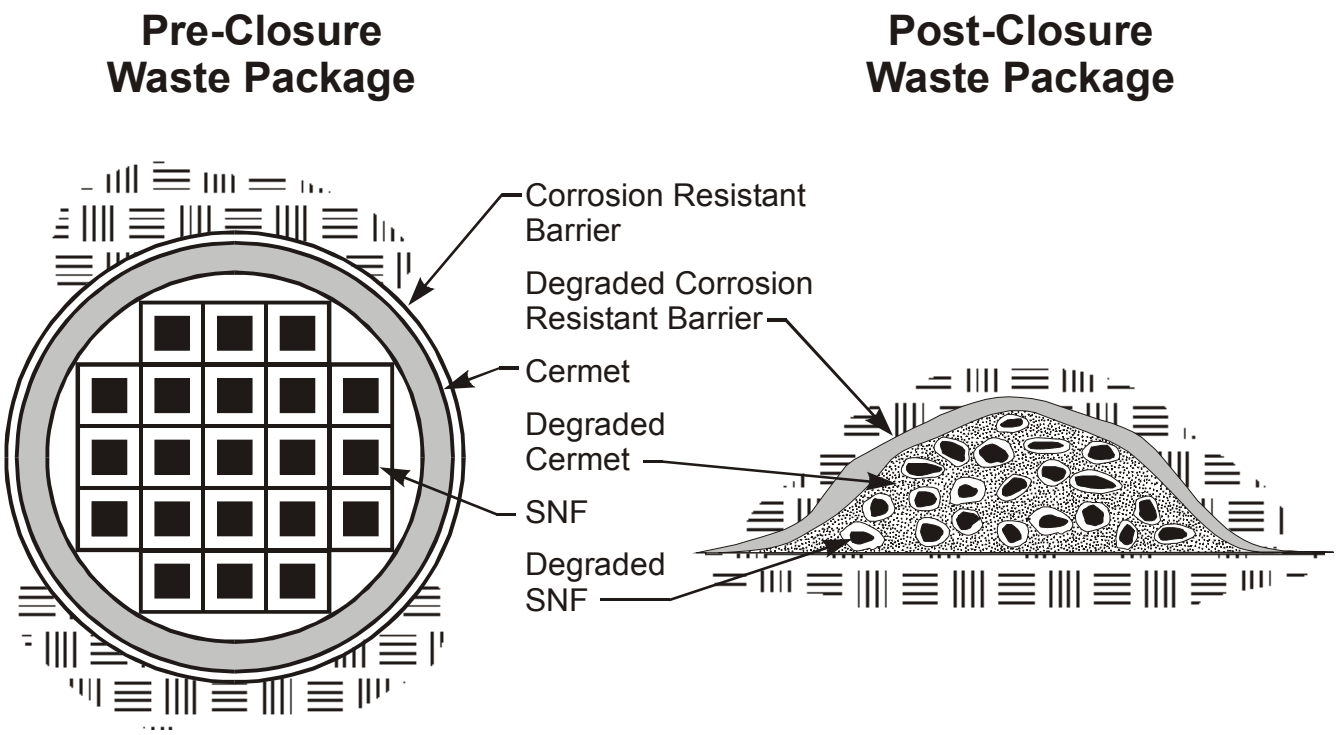
500,000 Tons of Excess DU Is Available
(Cermets Could Consume >50% of the Inventory)

Cermet Criticality Control Strategy

The Criticality Strategy Is To Overwhelm the Potential for Criticality with Depleted Uranium

- Shielded package has 3+ tons of depleted uranium per ton of SNF
- Average package enrichment: <<1%
- Quantity of cermet (depleted uranium) can be varied

Degradation Over Time Will Physically Mix and Then Isotopically Mix Depleted Uranium with Other Uranium Isotopes



Conclusions

- Multiple potential repository criticality control strategies exist
- Addition of depleted uranium avoids the need to predict long-term and far-field repository behavior to ensure criticality control
- This use of DU could consume one-half to all of the potentially excess DU inventory
- Further investigation is required to evaluate costs and benefits

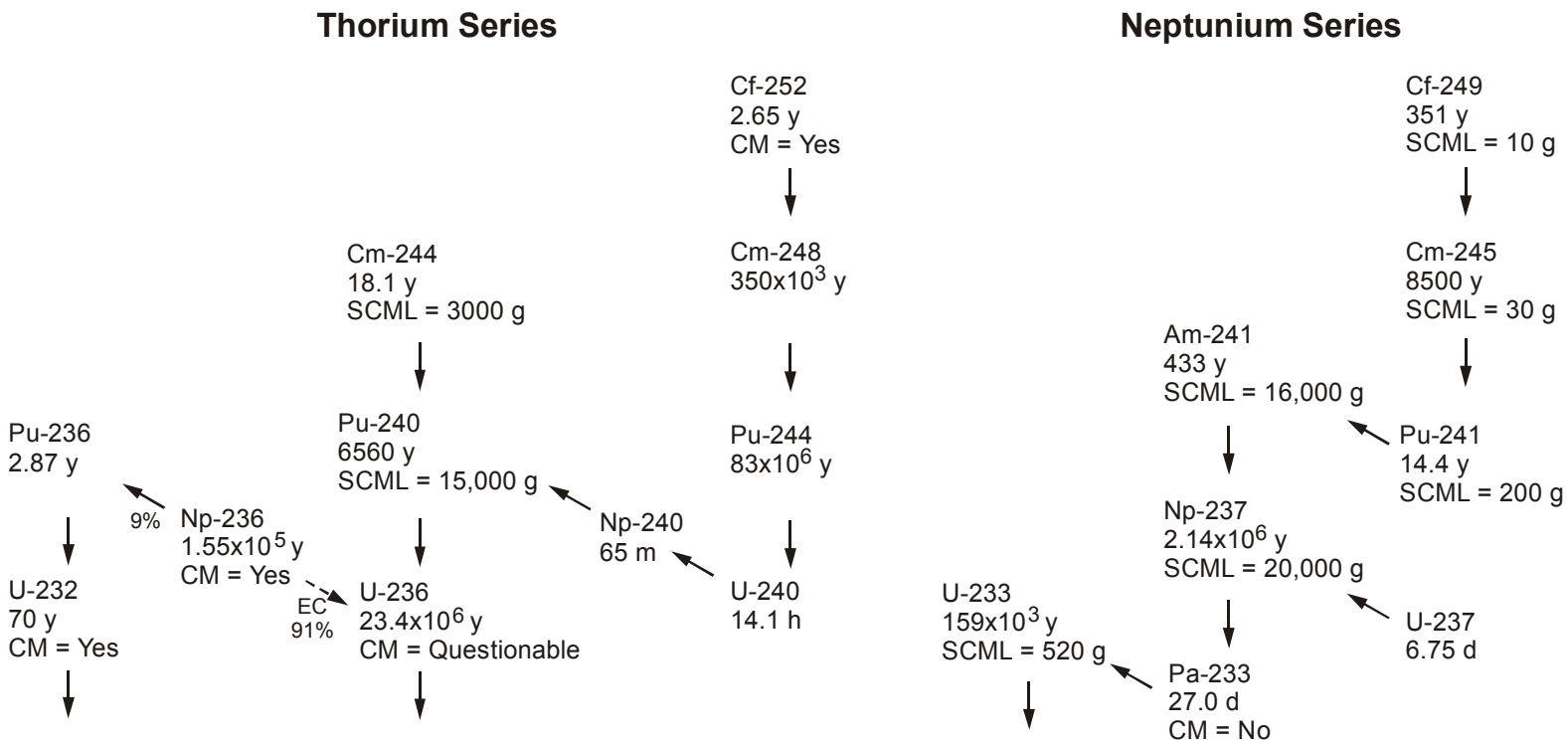
Additional Information

Four Benefits of Using DUO_2 in a Repository Waste Package

- Reduce potential for long-term nuclear criticality in the repository (today's talk)
- Reduce radionuclide release rates from SNF WPs
- Provide WP shielding
- Dispose of excess DU

Actinide Half-Lives and Geochemistry Imply That Repository Criticality Is Controlled by ^{233}U and ^{235}U

(Major Actinides [^{239}Pu, etc.] Decay to Uranium Fissile Isotopes)



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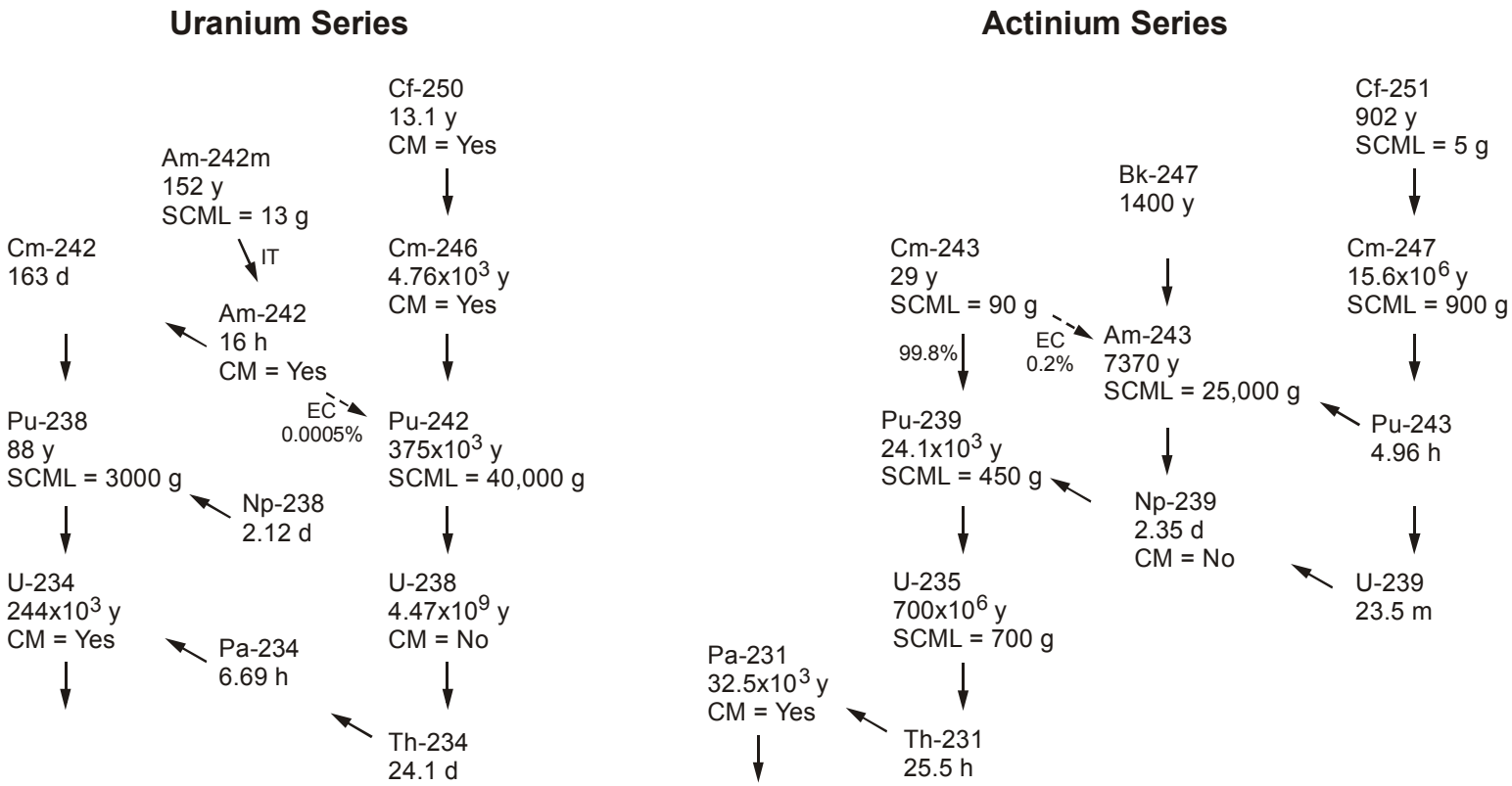

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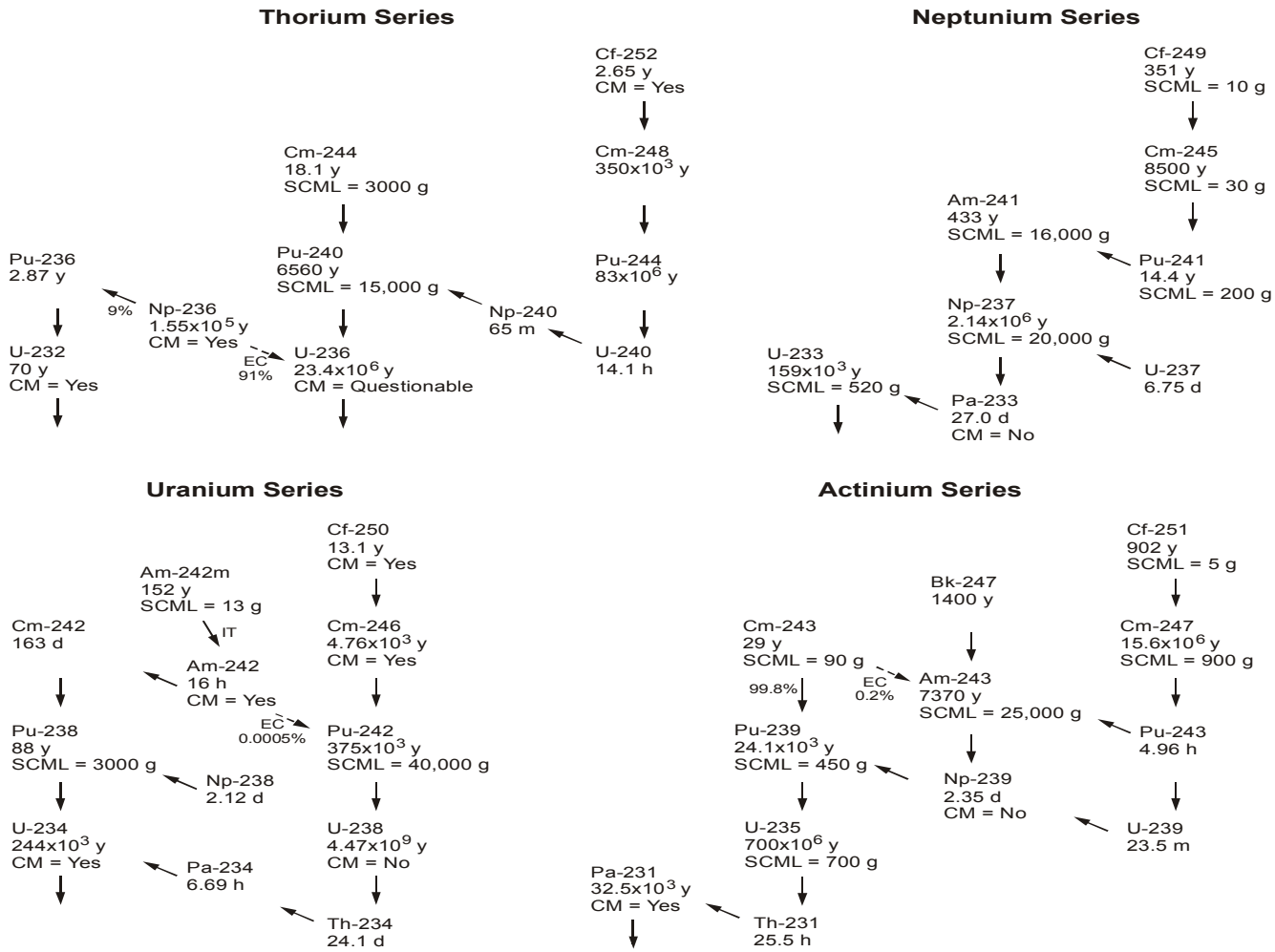

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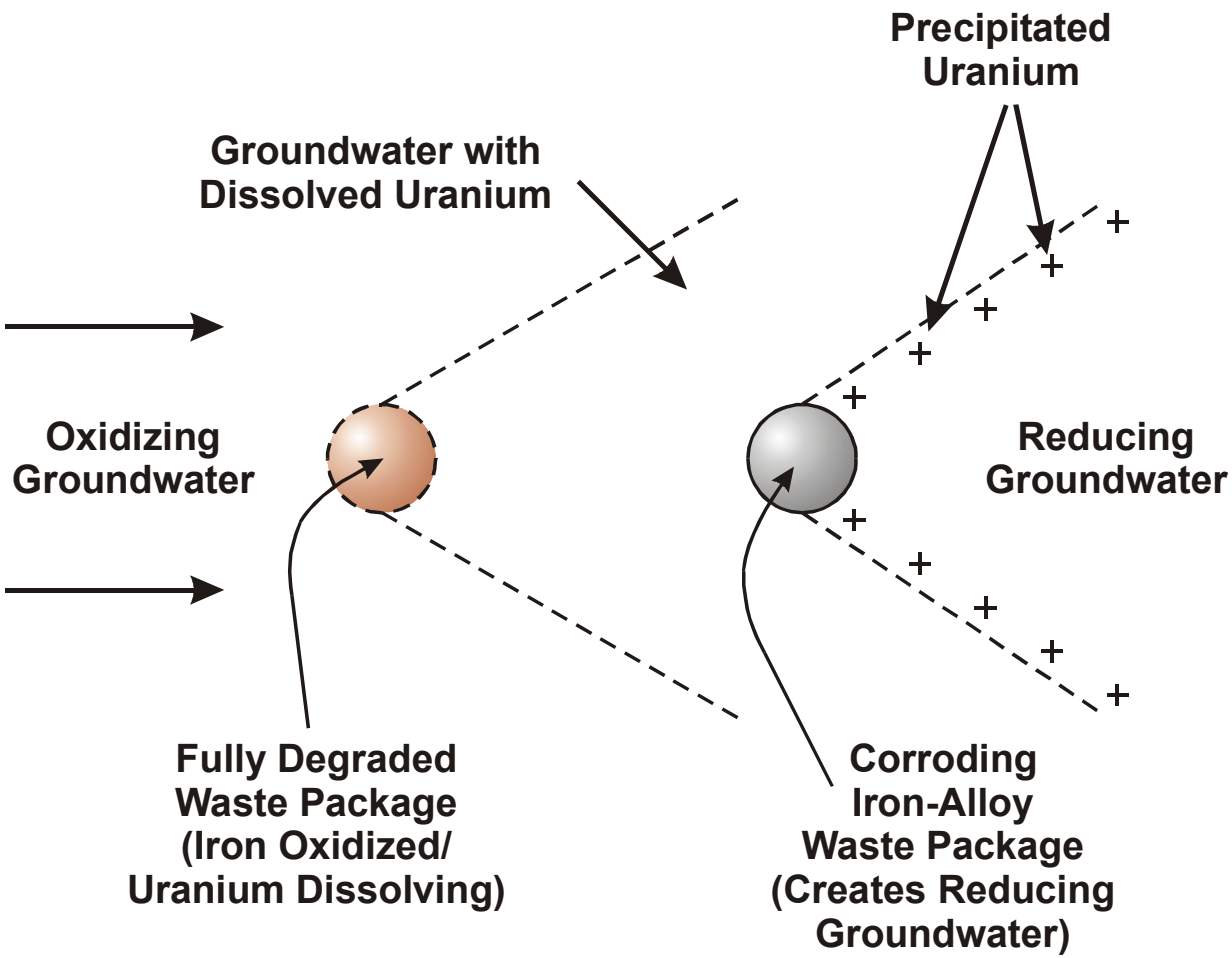
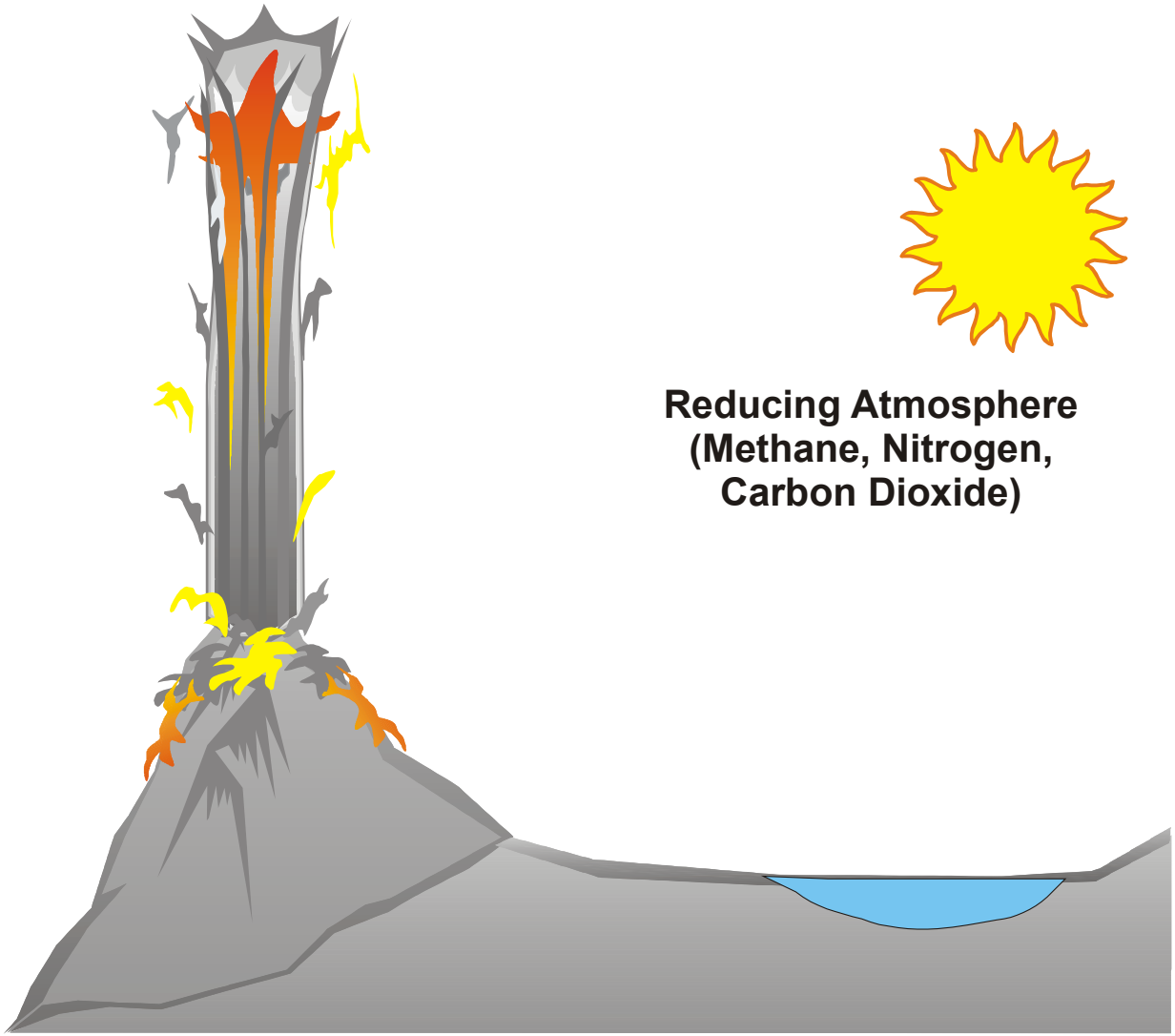
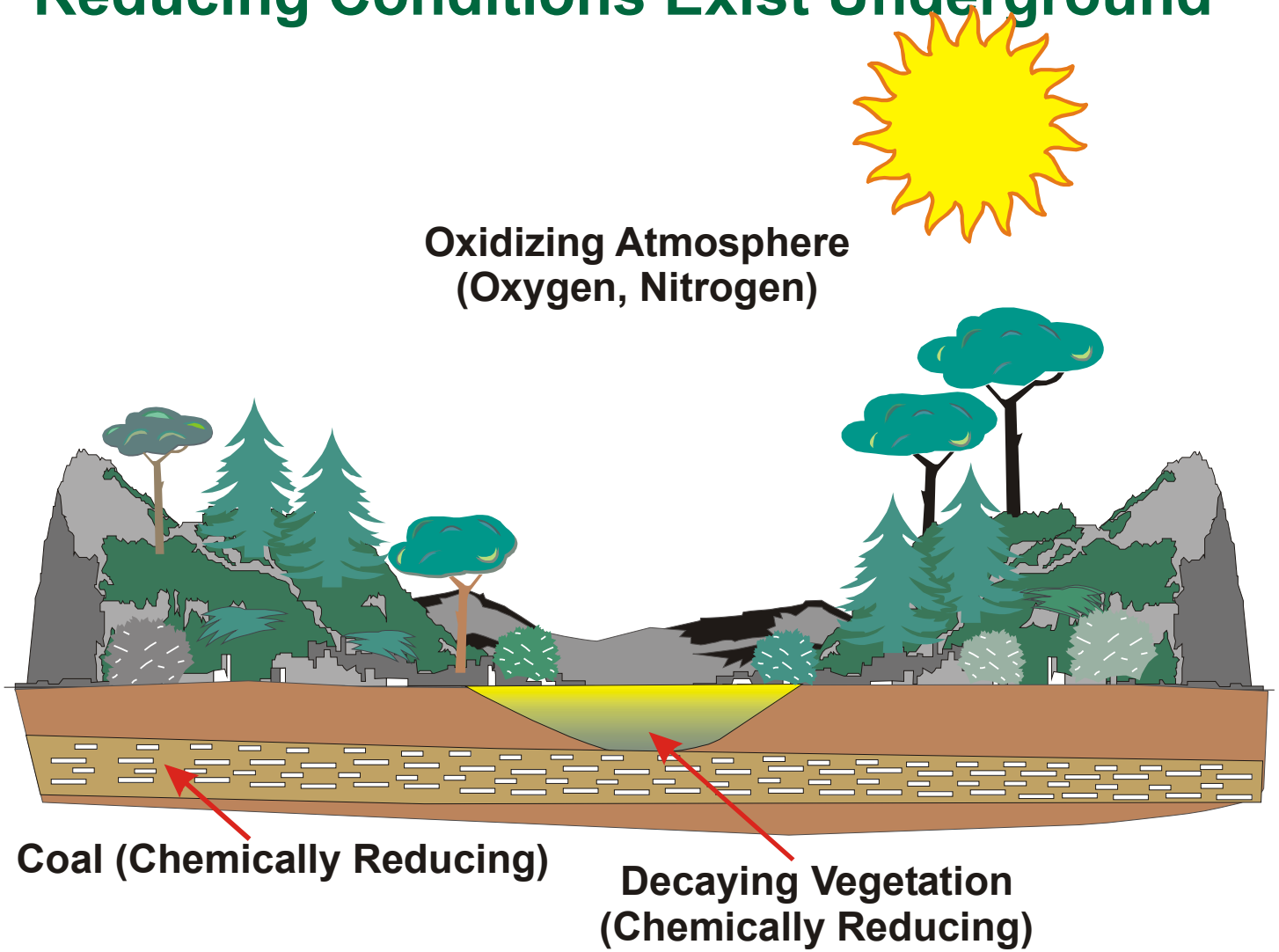
Uranium Can Dissolve and Precipitate in the Repository Near-Field Environment



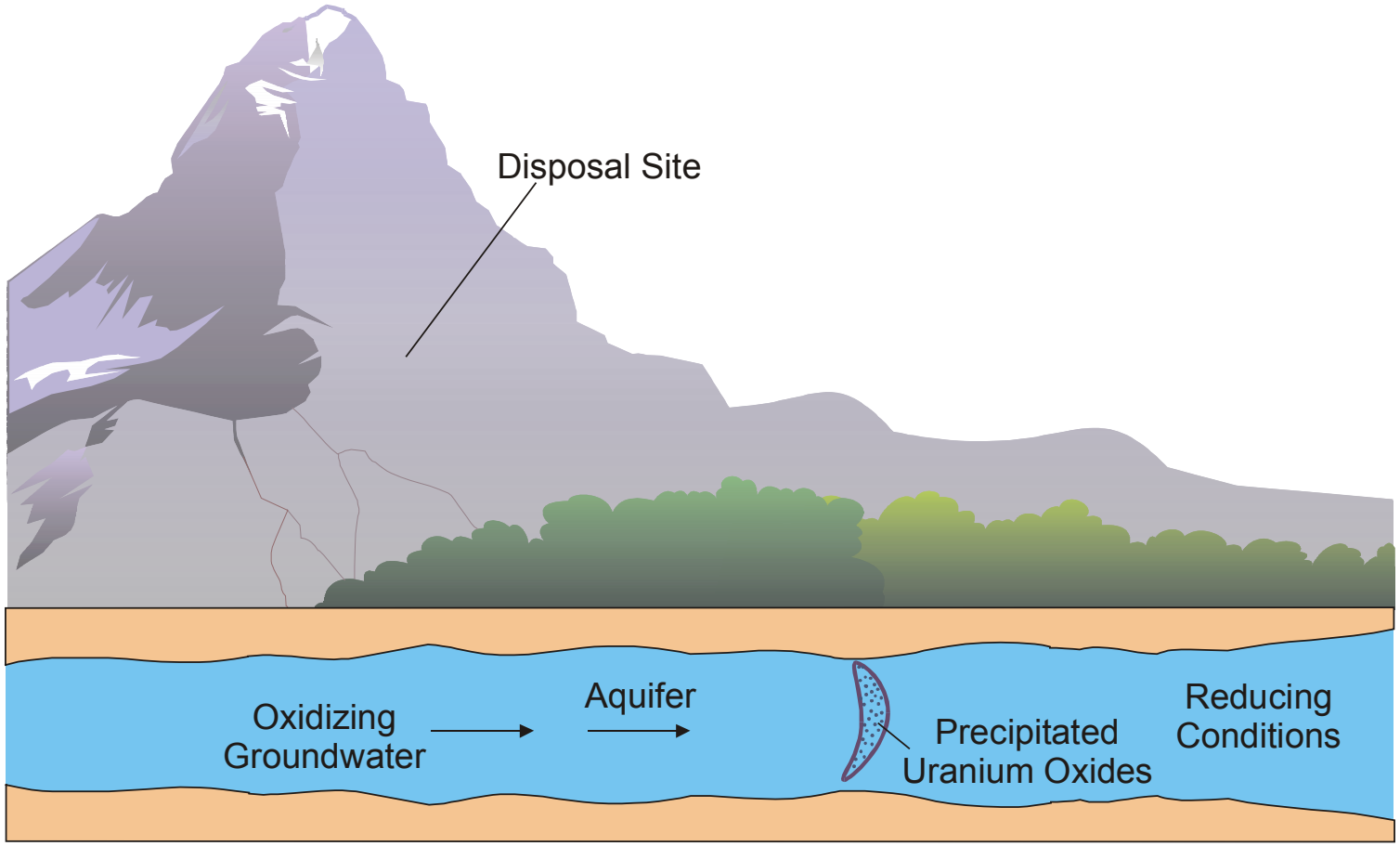
The Earth Initially Had a Chemically Reducing Environment with Little Uranium Migration



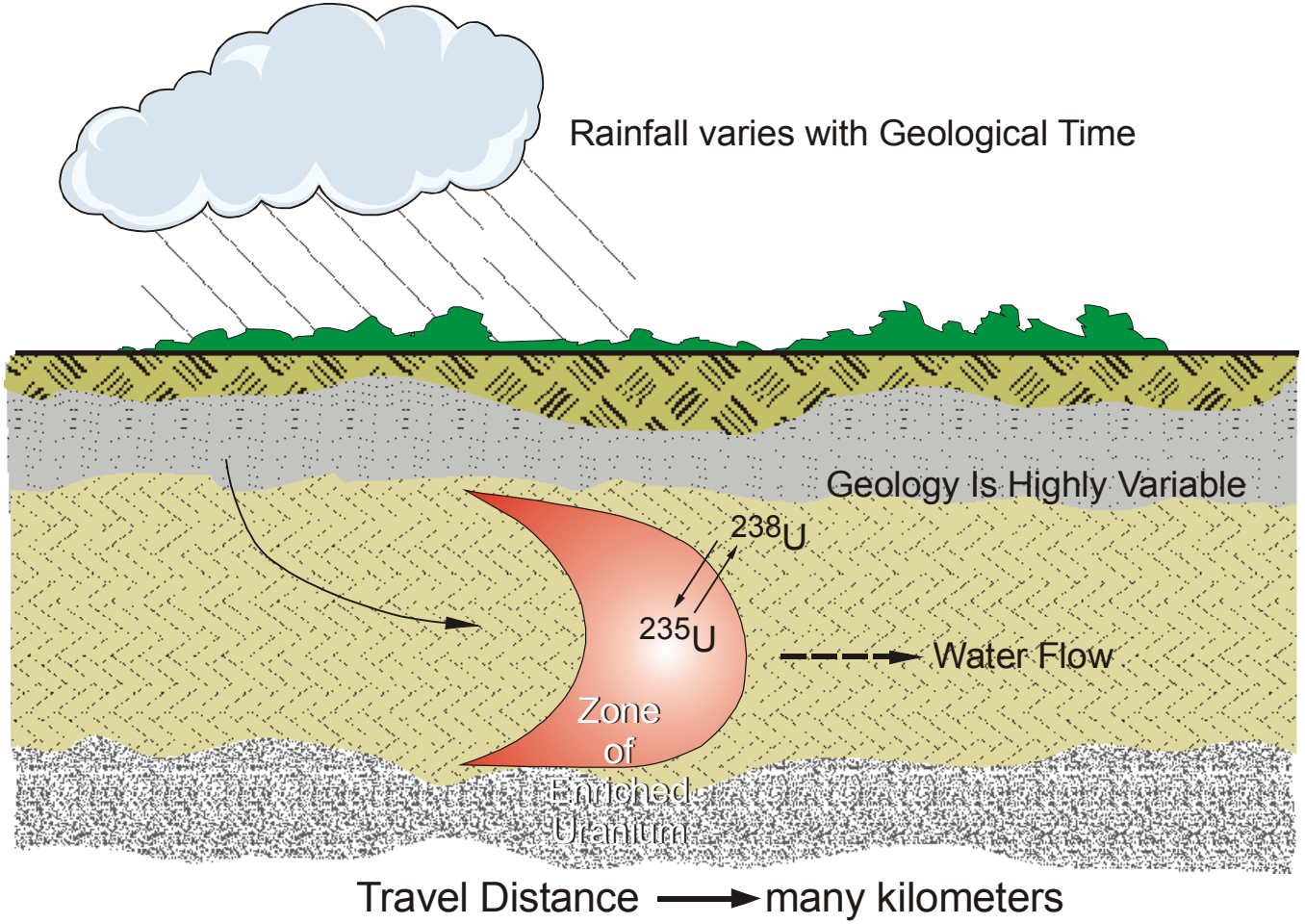
The Earth's Surface Is Oxidizing, But Chemically Reducing Conditions Exist Underground



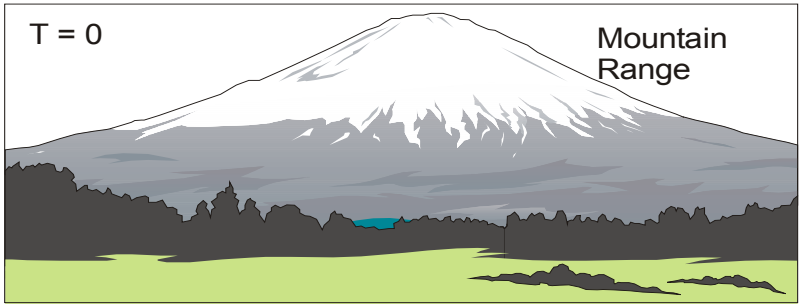
The Combination of Oxidizing and Reducing Environments Creates Mechanisms To Concentrate Uranium

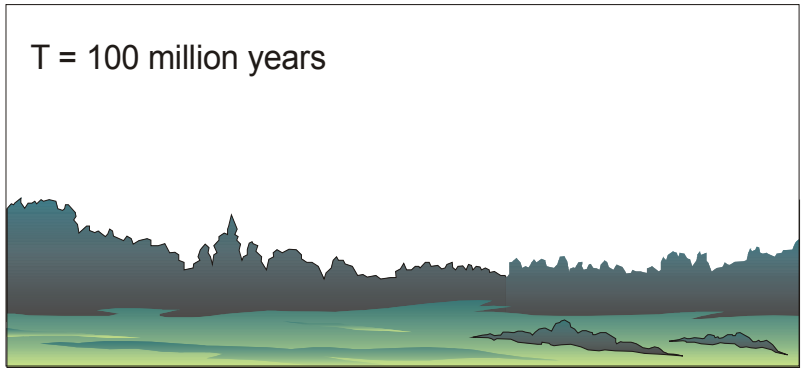


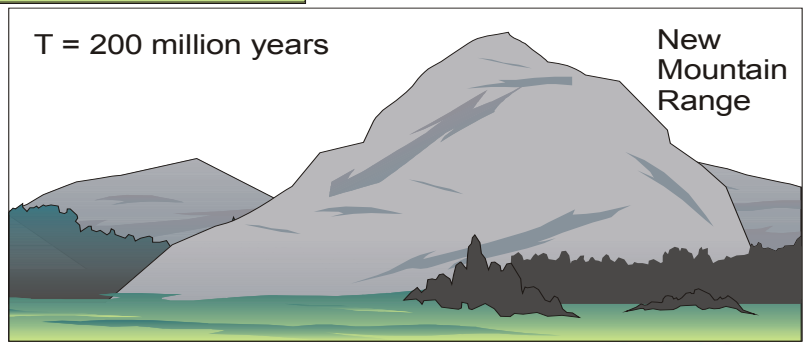
Roll Front Uranium Deposit



Enriched Uranium Is Destroyed More Rapidly by Isotopic Exchange Than by ^{235}U Decay







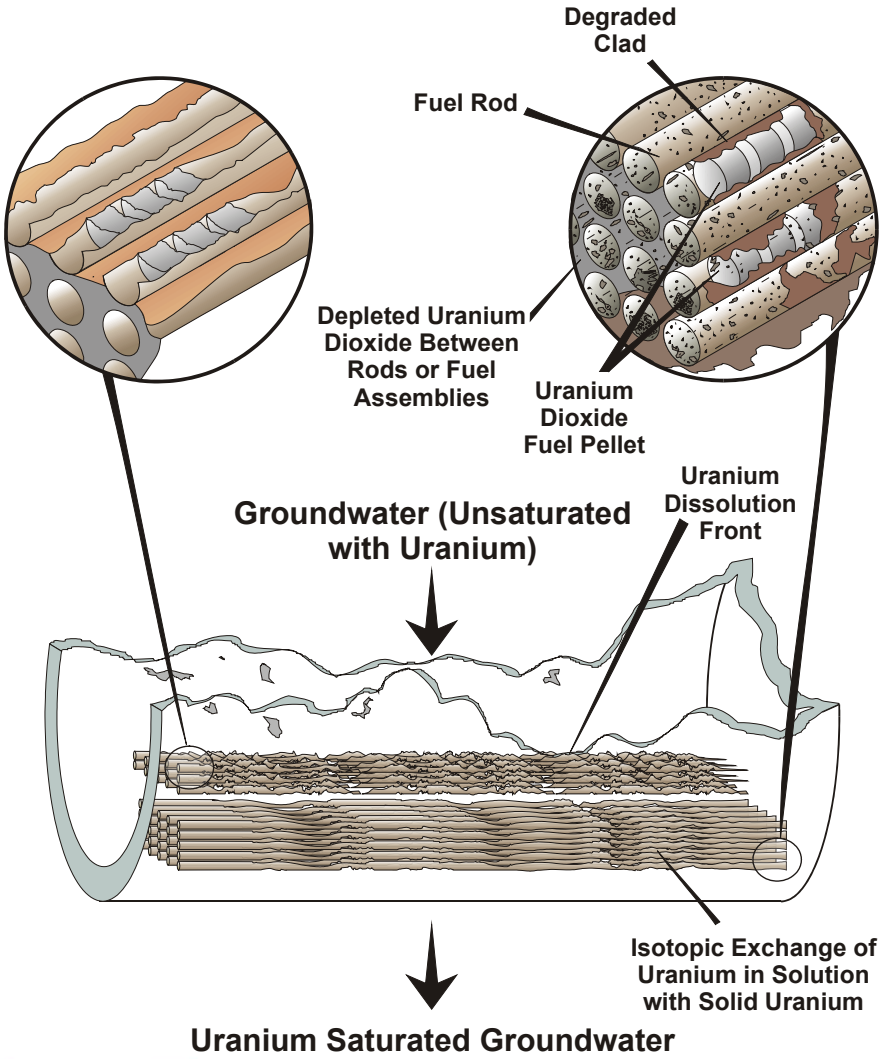
Methods To Demonstrate That Repository Criticality Will Not Occur

- Isotopically dilute fissile materials with DU
- Surround fissile materials with DU and show isotopic dilution as the package degrades (concept described herein)
- Dilute ^{235}U during uranium migration by isotopic exchange with ^{238}U in rock
  - Model SNF and WP degradation
  - Follow ^{235}U migration over time
  - Show that criticality does not occur

Cermet Waste Packages Can Minimize Long-Term Repository Nuclear Criticality Issues

- Fissile assay of commercial SNF is about 1.5 wt % ^{235}U equivalent
- Natural reactors (Oklo, Gabon) have occurred at uranium assays of ~1.3 wt %
- Cermets are a practical means of adding DU to the waste package to decrease fissile content to assured safe levels

Isotopic Dilution of SNF Uranium (Including Decayed ^{239}Pu) with DU Occurs with SNF/Cermet Degradation

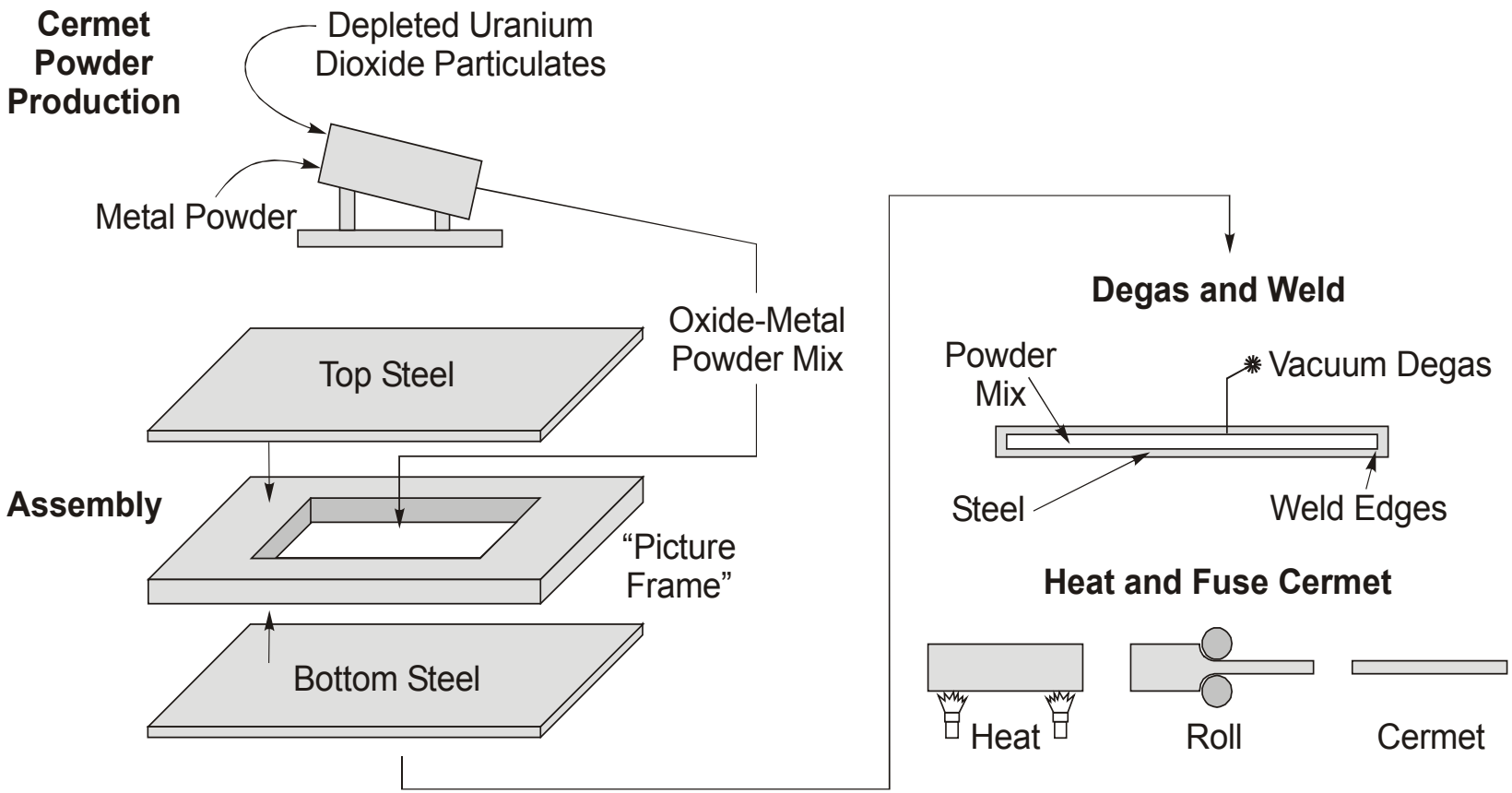


A Cermet Is a Ceramic-Metal Composite Material

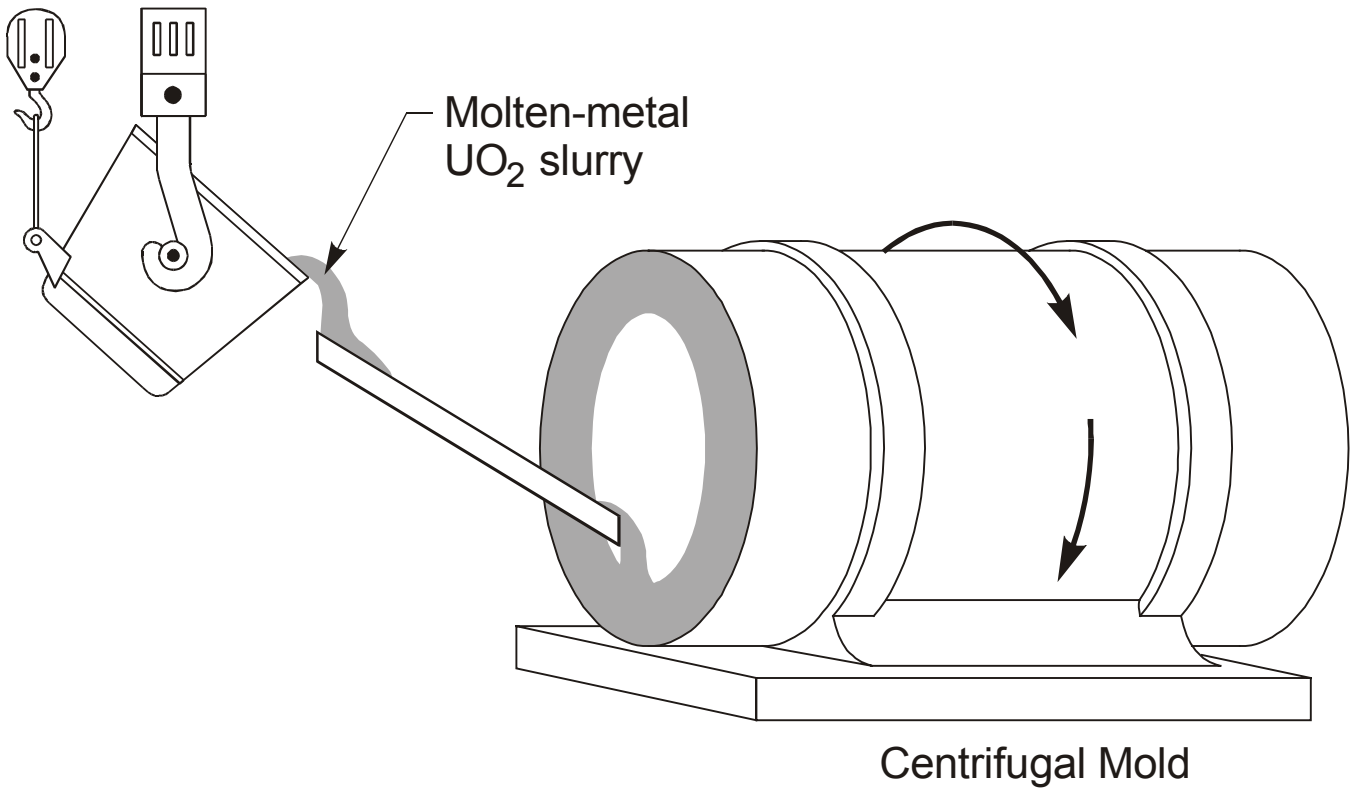
- Ceramic and metal are separate phases
- Properties are between those of ceramics and metals
- Large quantities of some cermets are produced (>10^5 t/year)
- A cermet for this application includes
  - Ceramic: DUO_2
  - Metal: steel (the continuous phase which is 35–50 vol % of the cermet)
- Multiple production techniques exist

"Picture-Frame" Method for Cermet Production

(Used for Some Nuclear Reactor Fuels and Some Nonnuclear Applications)



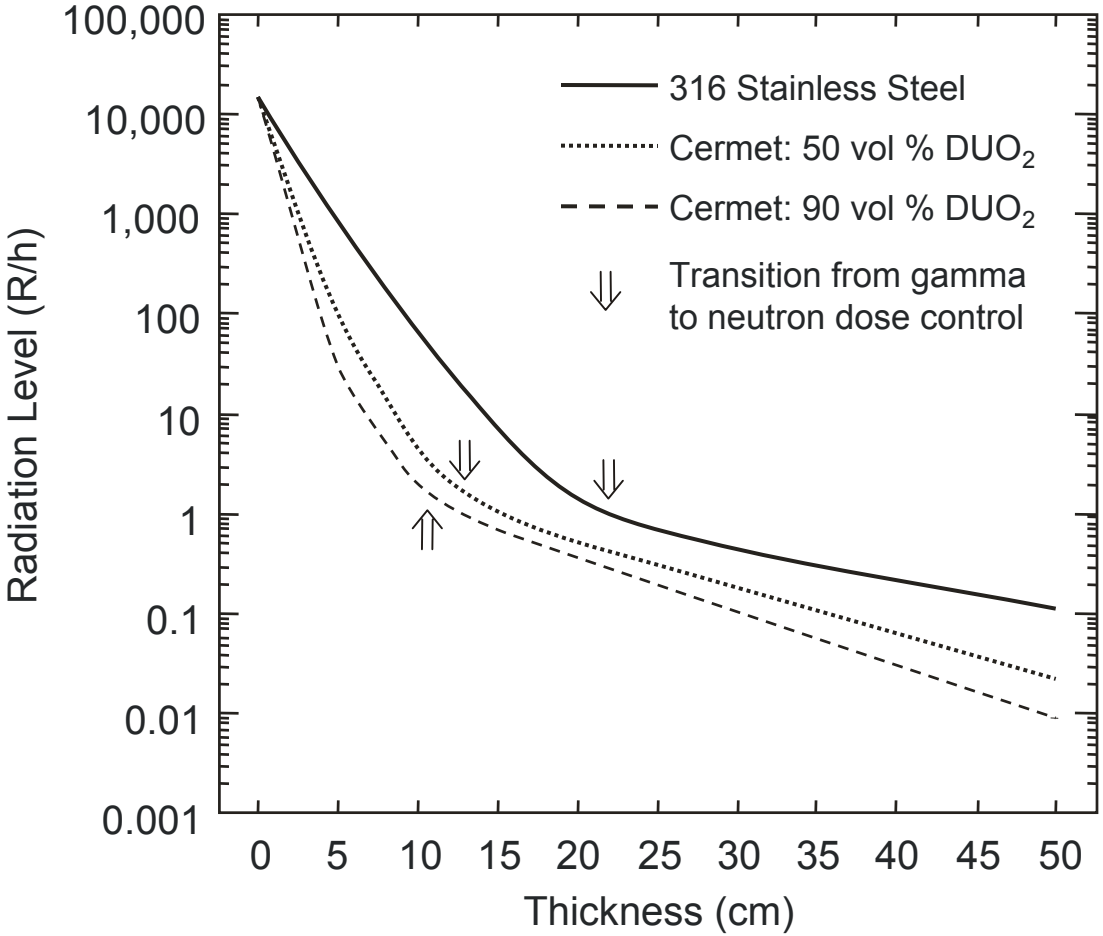
Spin Casting of Cermet Cask Body
(Future Option)



A DUO_2-Steel Cermet Is Compatible with the WP

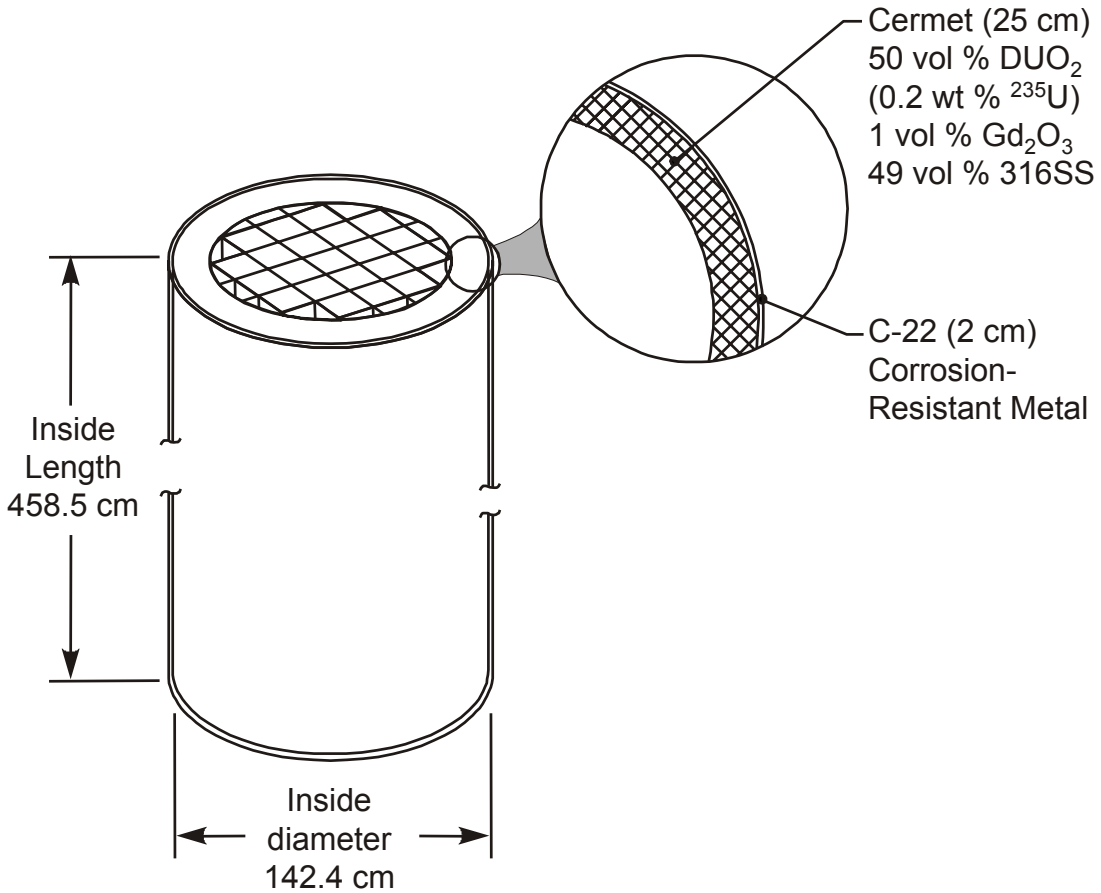
- Chemical compatibility is required
  - Cermet steel is compatible with a steel WP
  - DUO_2 is the same chemical form as is SNF UO_2
- Operations are simplified because DUO_2 is contained in steel (no contamination)
- A cermet allows a single material to meet multiple WP functional requirements
  - Structural strength (not possible with DUO_2)
  - Improved repository performance

Shielding Effectiveness (R/h) of Different Materials
(Source Term from 21-PWR Yucca Mountain Waste Package)



Example: Cermet-Shielded 21-PWR Yucca Mountain Waste Package

(>10,000 Required; Repository Metal of Choice Is 316 SS)



Cermets Have Advantages as Compared with Uranium Metal

- Better physical properties
  - Corrosion resistance
  - Adjustable properties
- U.S. Nuclear Regulatory Commission acceptance for repository applications and decommissioned-cask disposal
  - Uranium oxides acceptable
  - Unresolved issues with uranium metal

Sandwich Construction of Cermets

- Radioactive uranium is contained by exterior steel layers (no contamination)
- Construction maximizes strength, with strongest components on the outside
  - Interior steel layer
  - Cermet
  - Exterior steel layer

Cermets Can Be Made of Excess Materials: Disposal Costs Can Be Avoided

- Depleted uranium (>500,000 tons)
- Recycled steel (~2,000,000 tons)
  - From decommissioning of uranium enrichment and other nuclear facilities (low radioactivity)
  - Uncertainty of unlimited public recycle, recycle for nuclear applications accepted
  - Availability of large quantities of nickel, stainless steel, and other expensive metals
    - Allows use of high-performance "low-cost" alloys
    - Simplified manufacturing and licensing for ductile, high-performance alloys

Observations

- DUO_2-steel cermets can potentially replace structural, shielding, and basket components of casks and waste packages
- Multiple potential advantages exist
  - Shielding
  - Improved repository performance
  - Disposal of excess materials (DU and steel)
- Further examination of cermets is warranted for transport, storage, and disposal packages