Depleted Uranium Dioxide As SNF Waste Package Fill: A Disposal Option

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Outline

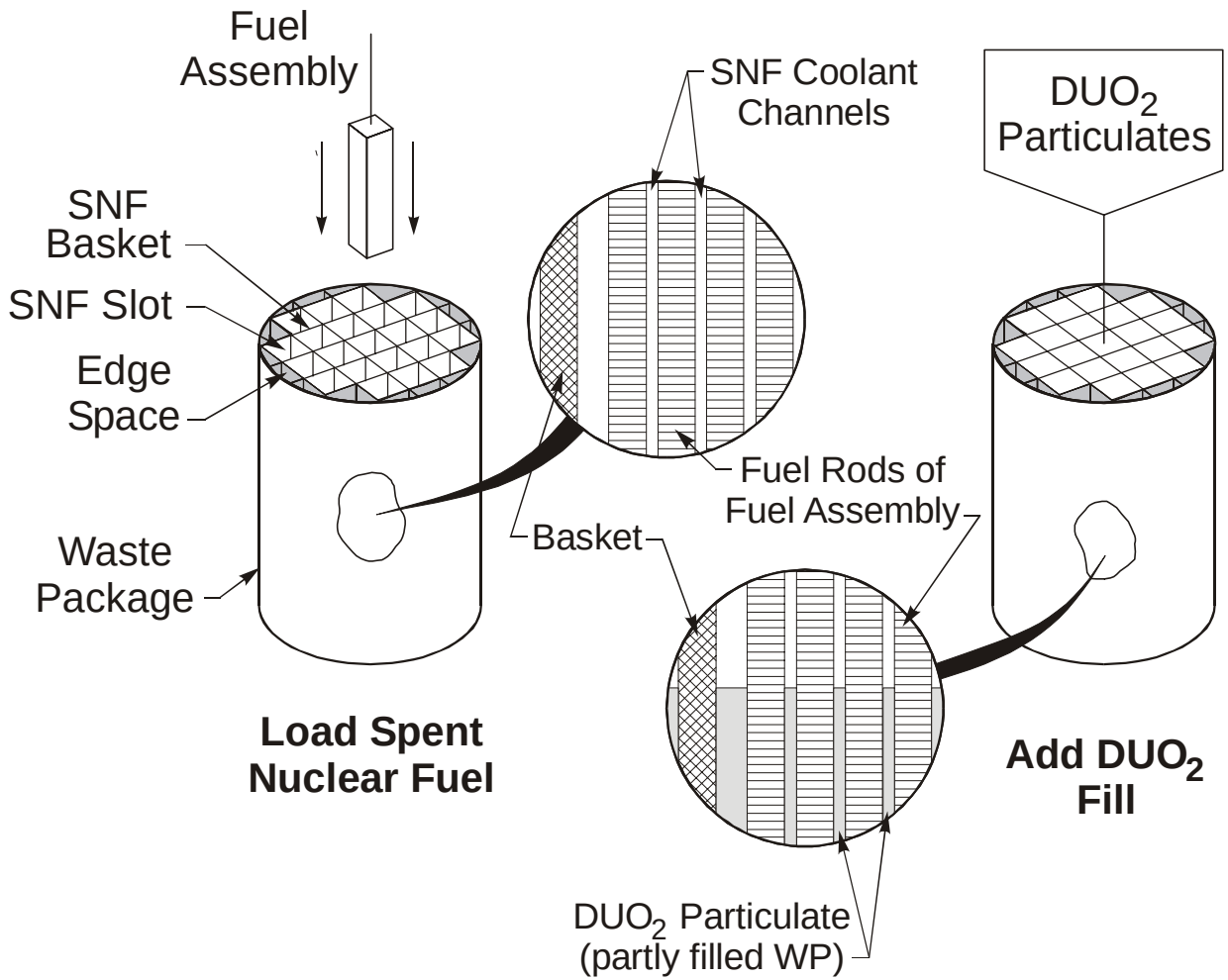
- **Applications for depleted uranium (DU) dioxide (DUO_2) in repository SNF waste packages (WPs)**
- **Benefits of using DUO_2**
- **Quantities of DUO_2 used**
- **Conclusions**

Applications For DUO_2 In Repository SNF WPs

Two Uses Have Been Identified For DUO_2 In A Repository WP

- **DUO_2 Particulate fill (0.5–1.0 mm) of void spaces**
  - **Spent nuclear fuel (SNF) coolant channels**
  - **Edge spaces**
- **DUO_2-steel cermet (DUO_2 embedded in steel)**
  - **WP basket**
  - **Structural components of package**

Waste Package Loading Sequence



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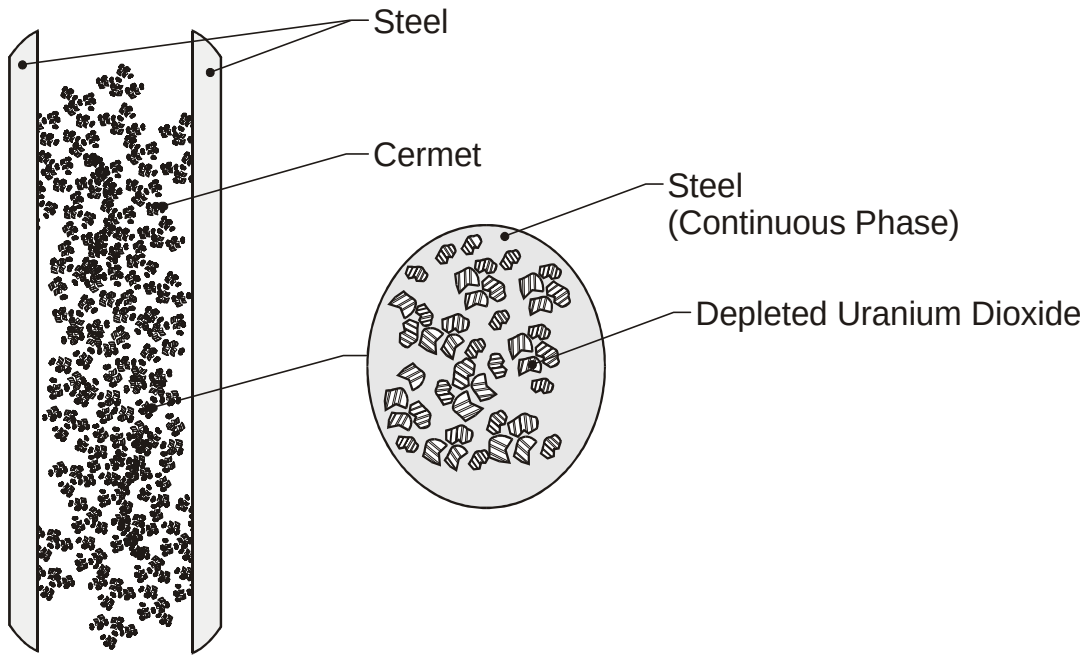

CERMET is a *CER*amic *MET*allic Composite

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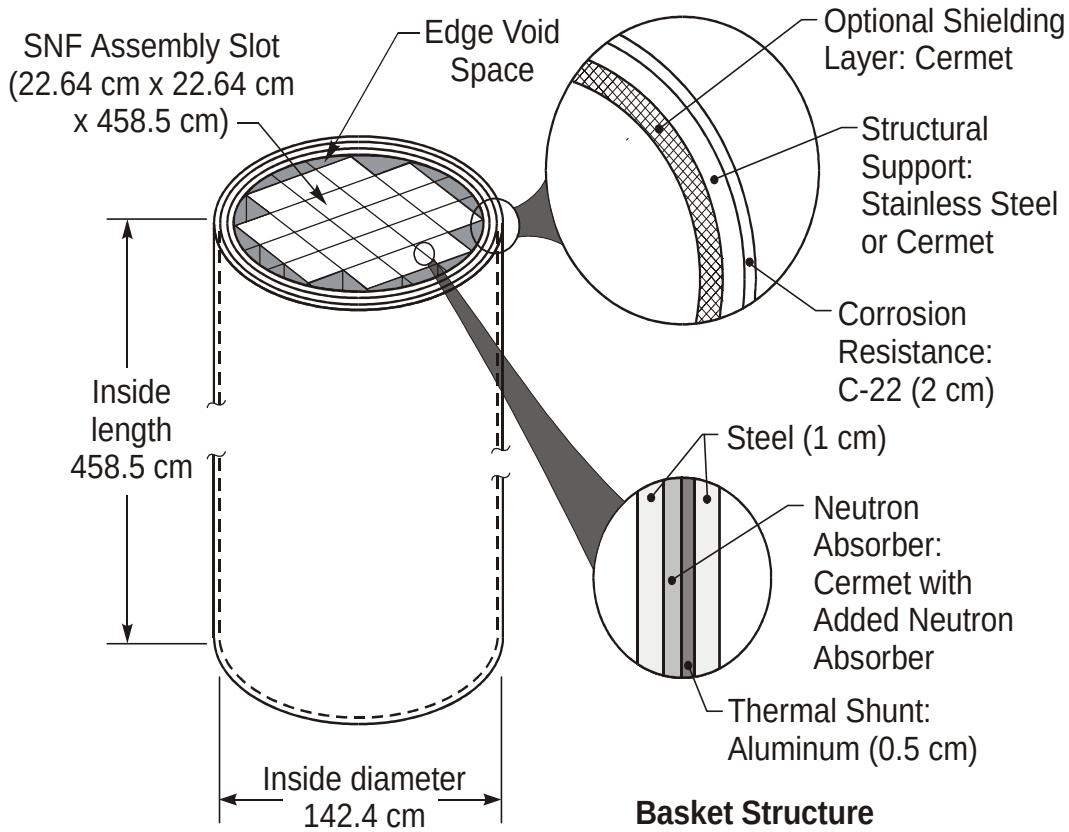


Uses of Cermet in PWR Fuel Assembly Waste Package

Benefits Of Using DUO_2

There Are Four Benefits Of Using DUO_2 In A Repository WP

- **Reduce potential for long-term nuclear criticality in the repository**
- **Reduce radionuclide release rates from SNF WPs**
- **Provide WP shielding**
- **Dispose of excess DU**

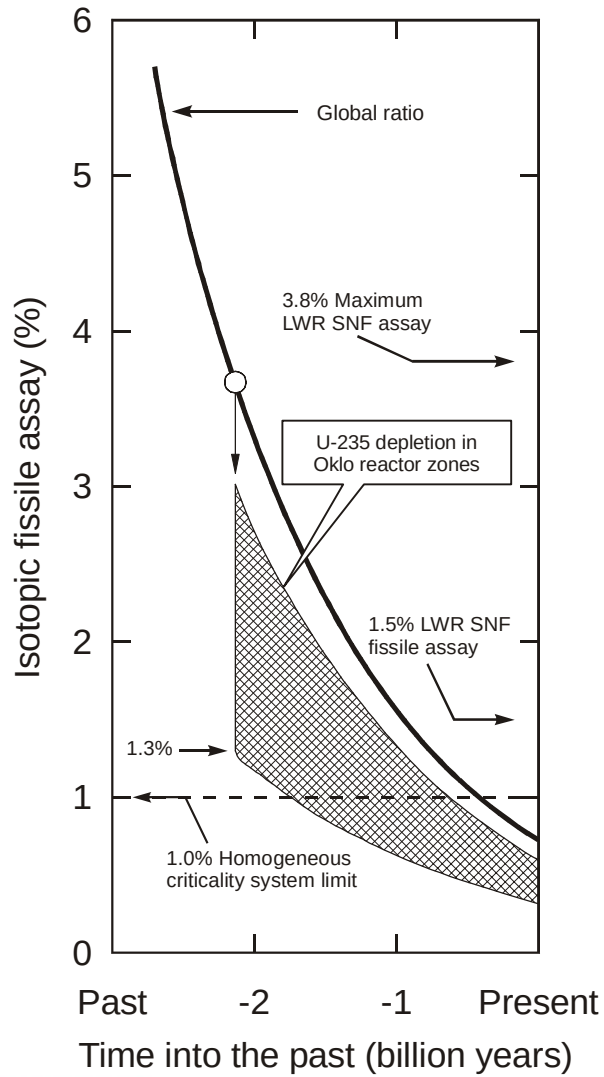
Benefits Of Using DUO_2

Reduce potential for long-term nuclear criticality in the repository

DUO_2 Reduces The Long-Term Potential For Nuclear Criticality In The Repository

- **Natural reactors (Oklo) have occurred with 1.3 wt % ^{235}U in ^{238}U**
- **Average fissile content of light-water reactor (LWR) SNF is ~1.5 wt % equivalent ^{235}U in ^{238}U: potential for criticality exists**
- **Other SNF has higher enrichment levels**
- **DUO_2 lowers WP enrichment so that criticality will not occur**

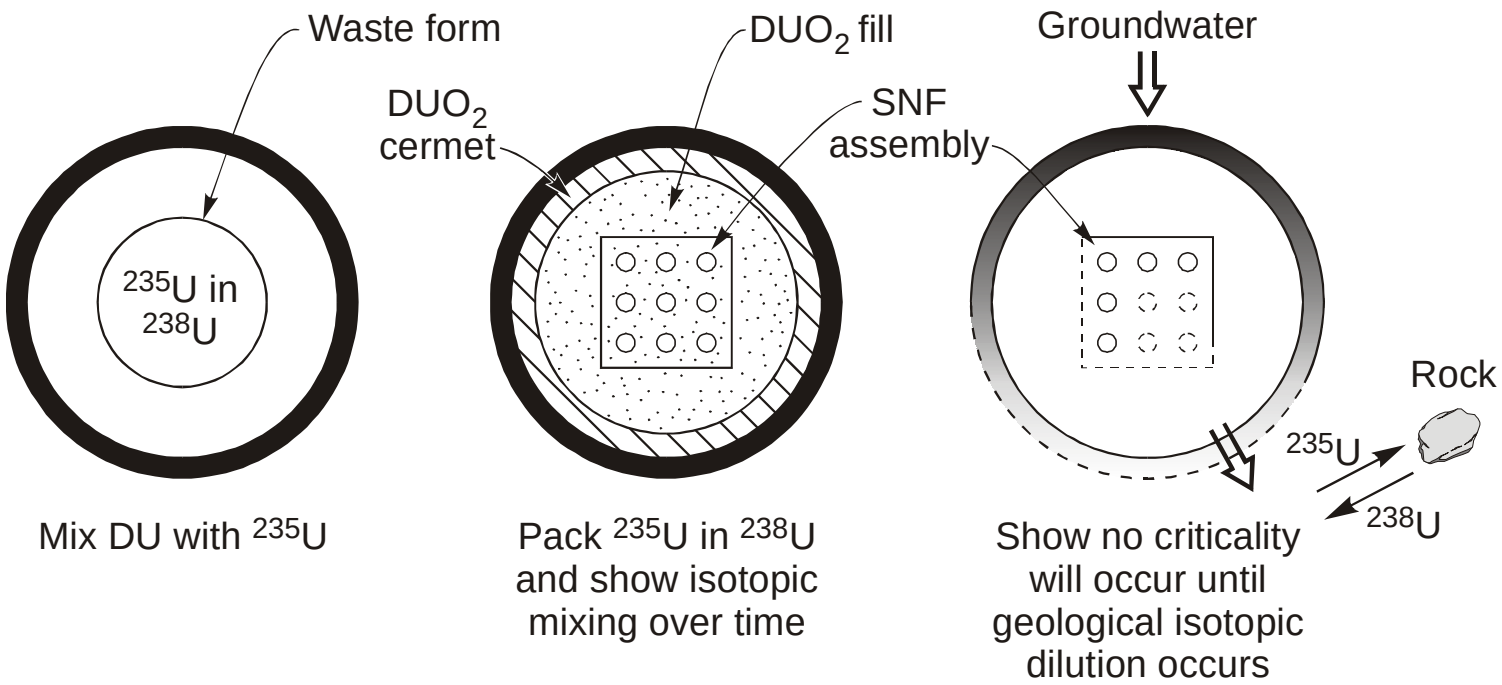
Natural Uranium Enrichment Levels Over Geological Time



Methods To Demonstrate That Repository Criticality Will Not Occur

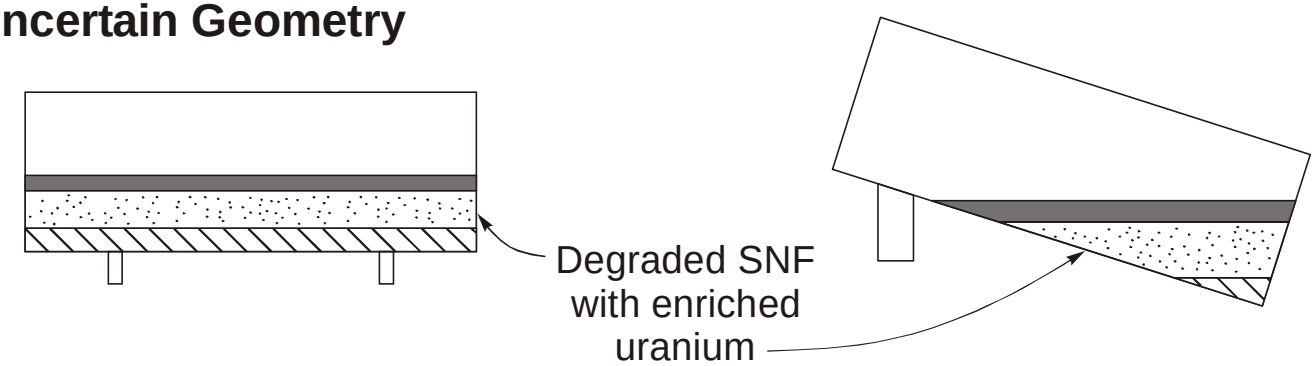
- **Isotopically dilute fissile materials with DU**
- **Surround fissile materials with DU and show isotopic dilution over time (concept described herein)**
- **Dilute ^{235}U during uranium migration by isotopic exchange with ^{238}U in rock**
  - **Model SNF and WP degradation**
  - **Follow ^{235}U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

Methods To Assure Nuclear Criticality Will Not Occur In A Repository

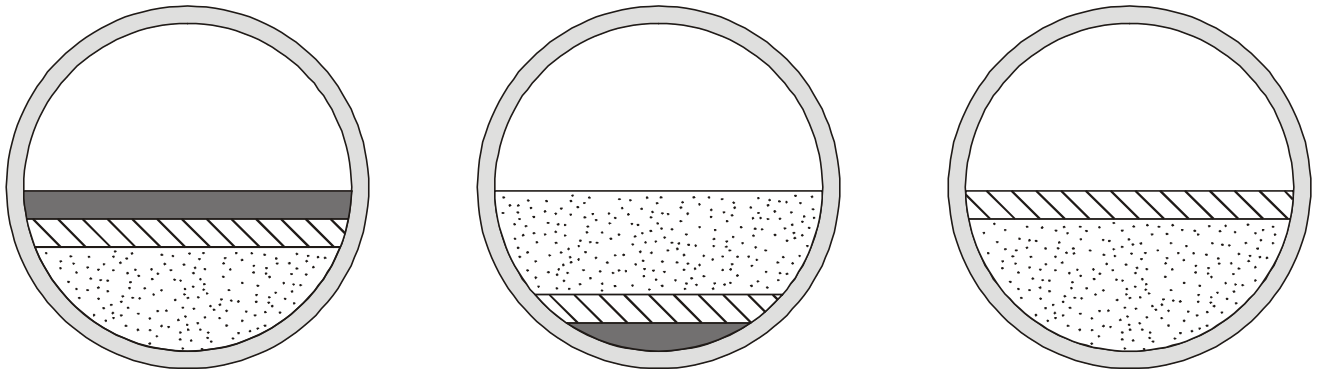


The Potential For Long-Term Near-Field Criticality In A Degraded Waste Package Is Difficult To Estimate

Uncertain Geometry

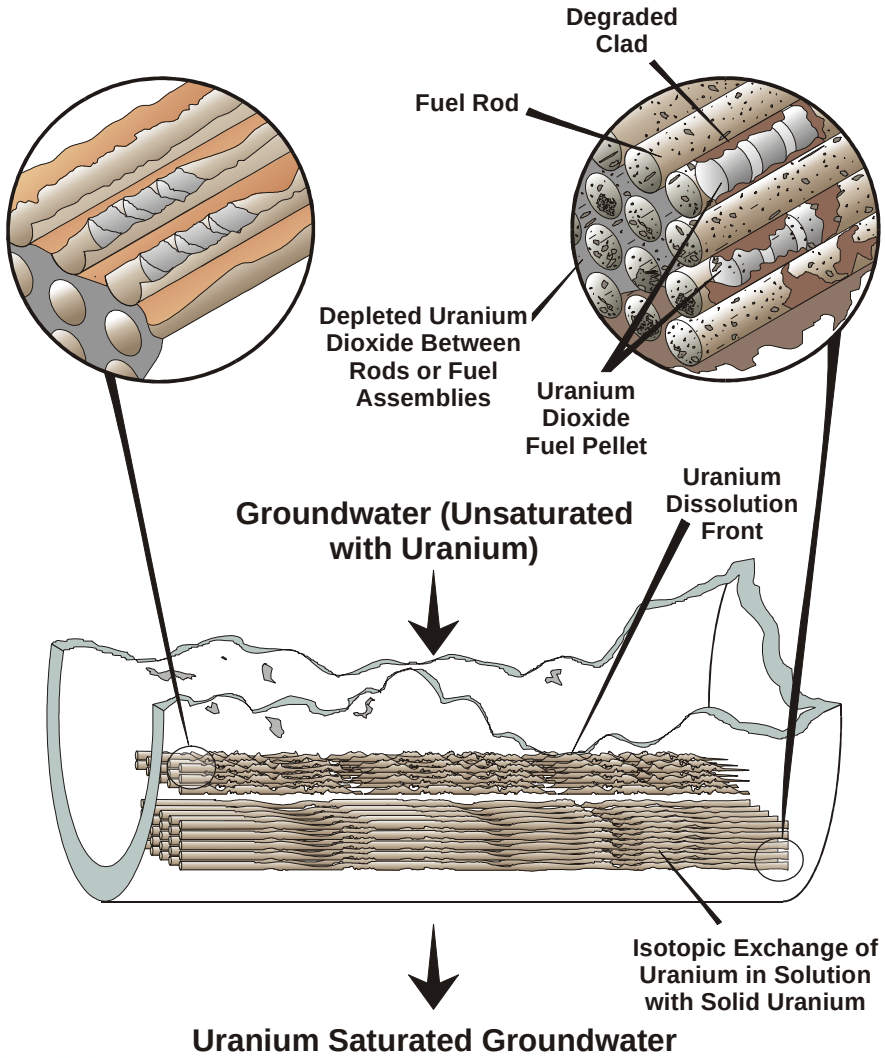


Uncertain Composition



Density separation | Particle size separation | Solubility (leaching) separation

Isotopic Dilution Of Spent Nuclear Fuel Uranium With Depleted Uranium



Benefits Of Using DUO_2

Reduce radionuclide release rates from SNF WPs

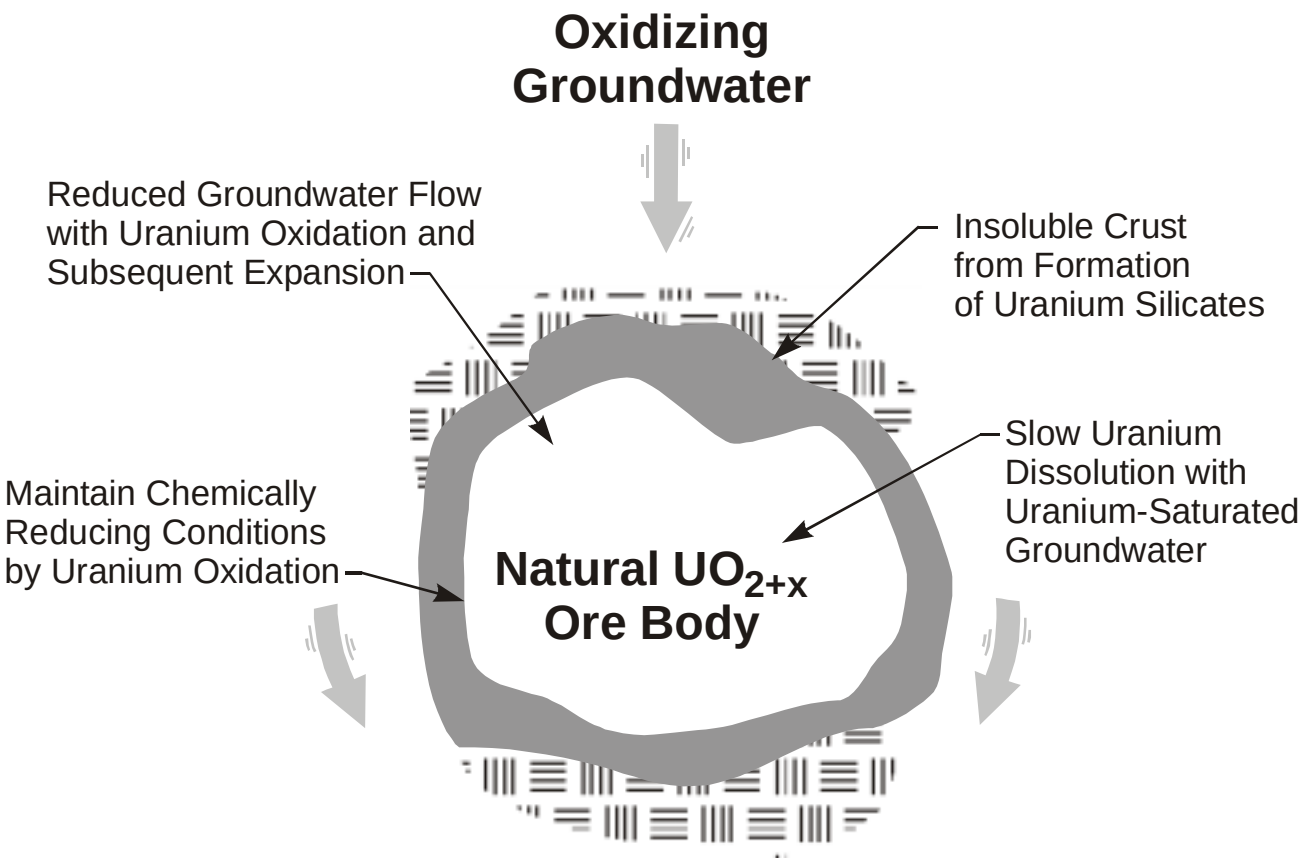
Delaying WP Radionuclide Releases Reduces Radionuclide Releases By Allowing For Radioactive Decay

- **Delay by preservation of SNF UO_2**
  - **Radionuclides are primarily incorporated into SNF UO_2 pellets**
  - **Radionuclides can not escape until SNF UO_2 pellets degrade**
- **Delay by retarding radionuclide movement**
  - **Minimize groundwater flow**
  - **Retard radionuclide migration in groundwater**

UO_2 Ore Deposits Have Existed For Long Times In Environments Similar To Yucca Mountain (YM)

- **UO_2 is chemically unstable in oxidizing environments such as YM**
- **SNF UO_2 oxidation will release radionuclides**
- **UO_2 ore deposits exist in such environments by sacrificial chemical reactions on the outer edges and elsewhere in the ore deposits**
- **The same mechanisms can be used to preserve SNF UO_2 with DUO_2 in the WP**

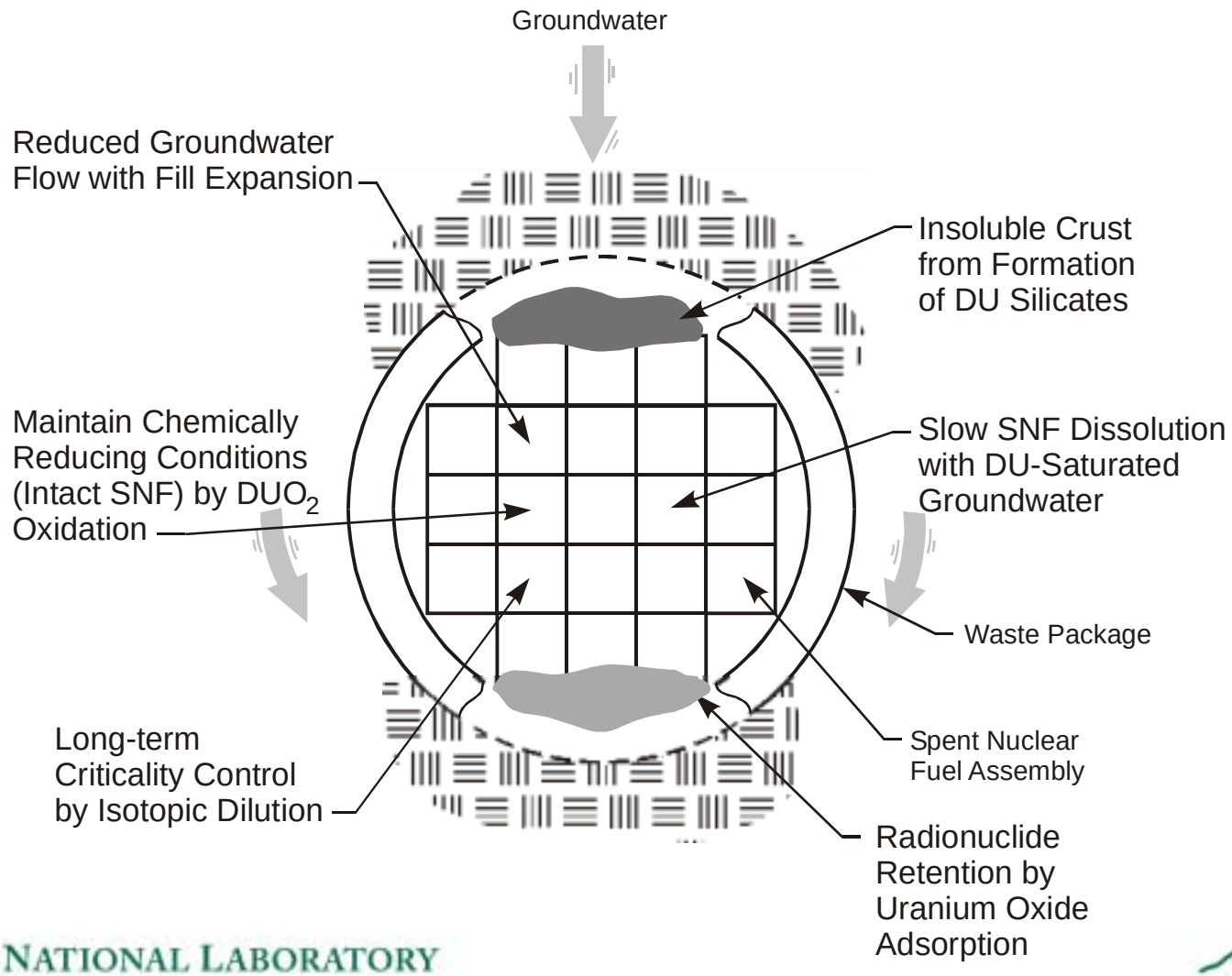
The Interiors Of Natural Uranium Ore Deposits Of Uranium Dioxide Are Preserved For Extended Times By Degradation Of Uranium Oxides On The Outside Surfaces Of The Ore Deposit



DUO_2 Slows SNF WP Radionuclide Releases By Multiple Mechanisms

- **Delay by preservation of SNF UO_2**
  - **Maintain chemically reducing conditions in WP**
  - **Saturate groundwater with DUO_2 to slow SNF UO_2 dissolution**
- **Delay by retarding radionuclide movement**
  - **Reduce fluid flow through SNF and WP**
  - **Retard radionuclide transport in groundwater**
    - **Ion-exchange and absorption of radionuclides on DUO_x**
    - **Filter radioactive colloids from groundwater**

Spent Nuclear Fuel Waste Package With Depleted Uranium Dioxide Particulate Fill To Improve Repository Performance



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Benefits Of Using DUO_2

Provide WP shielding

DUO_2 Is An Effective Radiation-Shielding Material

- **DUO_2 provides gamma-radiation shielding and limited neutron shielding**
- **DUO_2 fill provides some shielding**
- **DUO_2 cermets can provide full gamma-radiation shielding**
  - **Density: 25% higher than steel**
  - **Cask weight: ~100 t for a self-shielded WP**

Benefits Of Using DUO_2

Dispose of excess DU

Use Of DUO_2 Provides A Disposal Method For Excess Depleted Uranium (DU)

- **Growing inventory**
  - **4 to 6 t of DU produced per tonne of LWR fuel**
  - **Worldwide inventory ~10^6 t (40% in U.S.)**
  - **Low consumption (~10^3 t/year)**
- **Geological disposal is a preferred option**
  - **Meets all disposal requirements**
  - **Oxide is the preferred form (no compatibility issues and same chemical form as that of SNF)**

Quantities Of DUO_2 That May Be Consumed For Different WP Designs

Ground Rules For Evaluating DUO_2 Use In An SNF WP

- **Assume standard Yucca Mountain WP for 21 PWR fuel assemblies**
- **More DUO_2 is better**
- **DUO_2 quantities are limited by:**
  - **Available void volume (fill applications)**
  - **WP gross weight (fill and cermet applications)**
    - **100 t (self-shielded WP)**
    - **125 t (largest transport cask weight)**

Quantities Of DUO_2 Used For Different WP Designs

Type	DUO_2 (t)	Ratio (DU:SNF)	Gross Weight (t)
Fill (all voids)	33.1	3.46	75.4
Self-shielded (Fill & Cermet)	49.1	5.14	100
Maximum Weight (Fill & Cermet)	65.4	6.84	125

Conclusions

- **There are multiple potential repository benefits in using DUO_2 in WPs**
- **DUO_2 can be added to WPs in two forms:**
  - **Fill**
  - **Cermet**
- **This use of DU could consume half to all of the potentially excess DU inventory**
- **Added work is required to evaluate costs and benefits**

Backup Information

DUO_2 Is The 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**
- **Cermet manufacturing may require DUO_2**
  - **Other uranium oxides decompose to UO_2 upon heating**
  - **Cermet manufacturing methods usually require high processing temperatures**

A Cermet Is A Ceramic-Metal Composite Material

- **Ceramic and metal are separate phases**
- **Properties between 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 that is 35–50 vol % of the cermet)**
- **Multiple production techniques exist**

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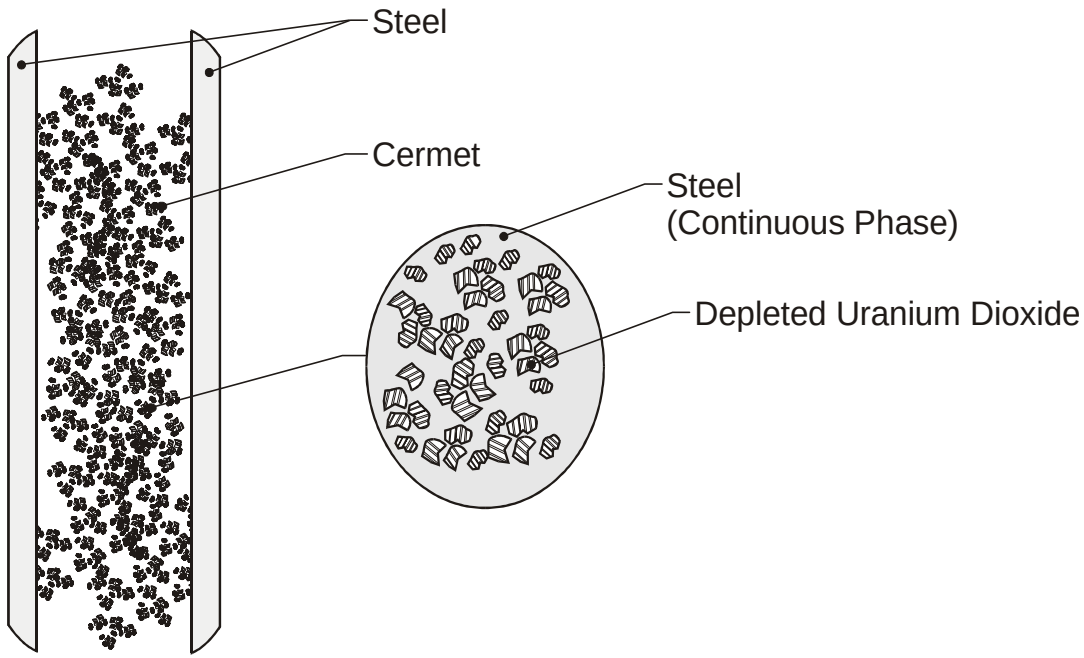

CERMET is a *CER*amic *MET*allic Composite

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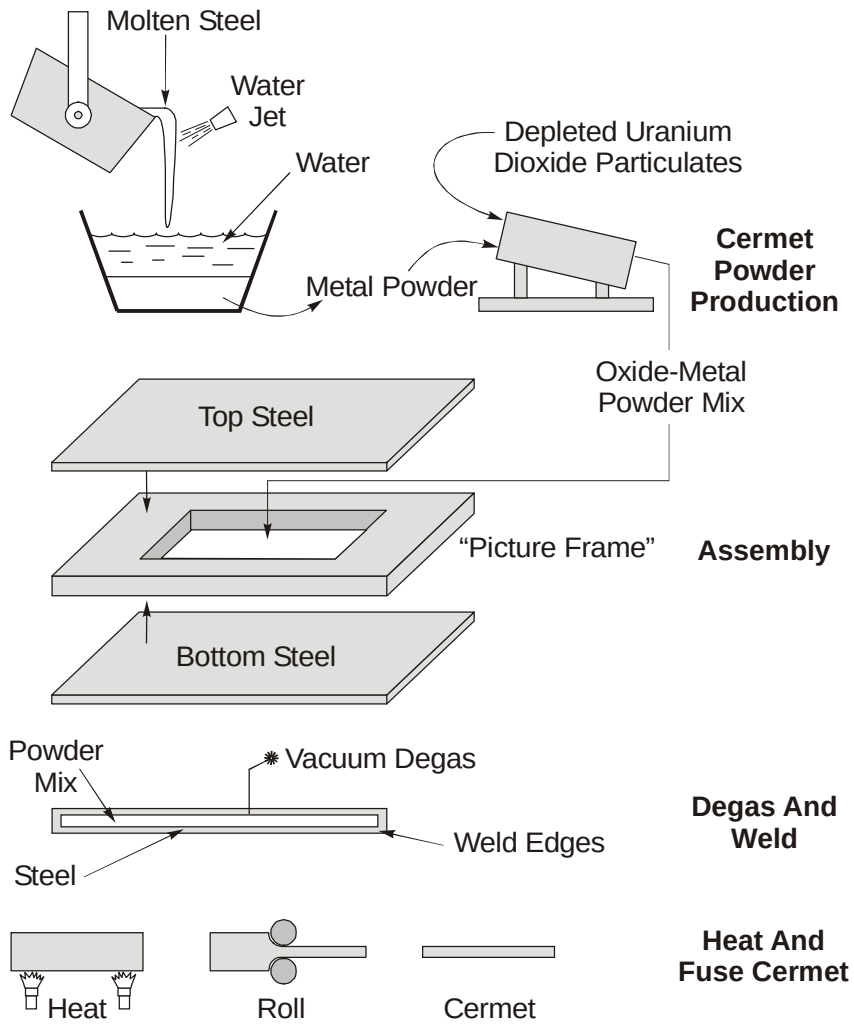


Example Method for Cermet Production

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**
- **Simplified operations because DUO_2 is contained in steel (no contamination)**
- **A cermet allows a single material to meet multiple WP functional requirements**
  - **Structural strength**
  - **Improved repository performance**

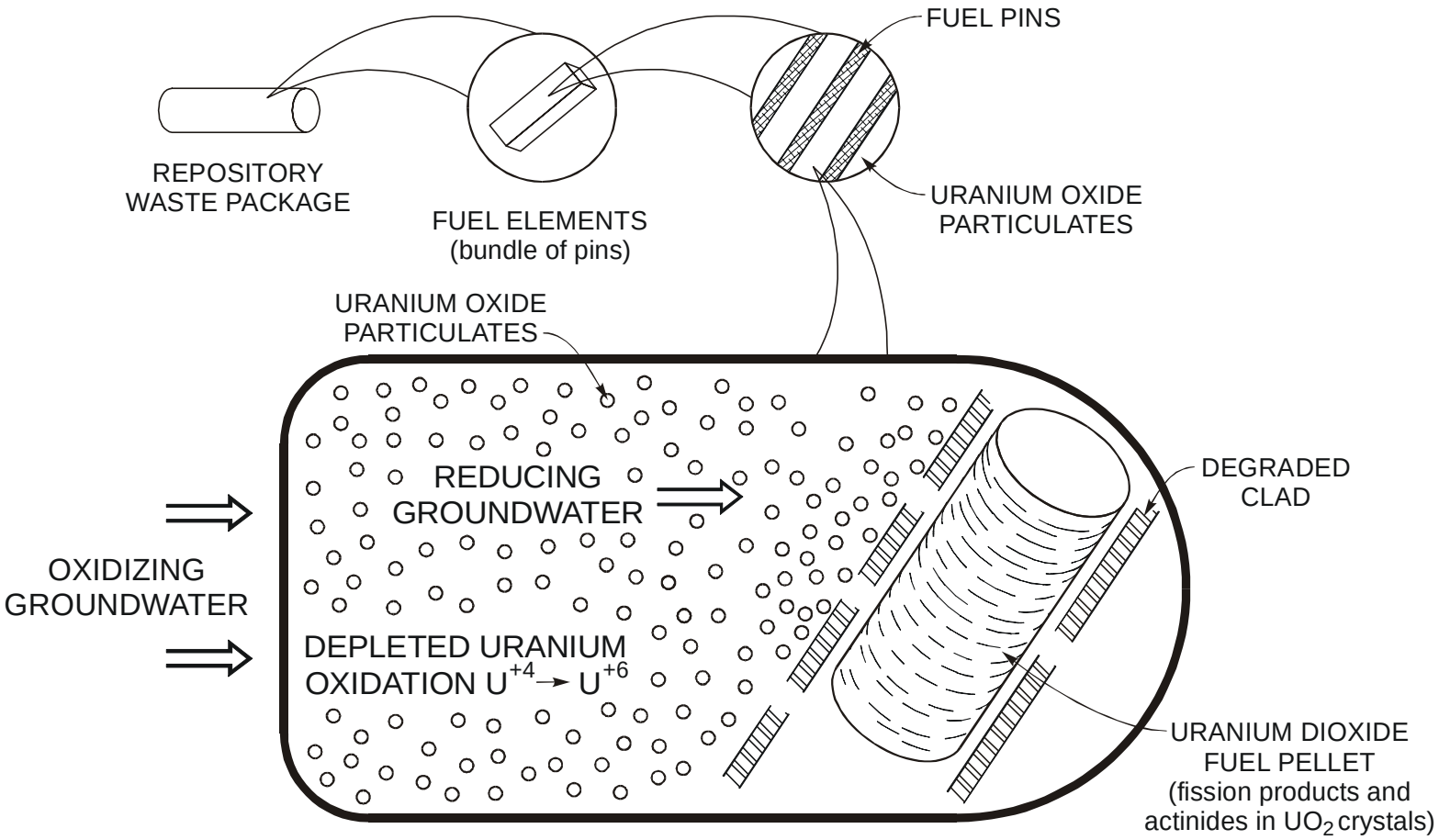
DUO_2 Reduces SNF WP Radionuclide Releases By Providing Time For Radioactive Decay

- **Delay by preservation of SNF UO_2**
  - **Maintain chemically reducing conditions in WP**
  - **Saturate groundwater with DUO_2 to slow SNF UO_2 dissolution**
- **Delay by retarding radionuclide movement**
  - **Reduce fluid flow through SNF and WP**
  - **Retard radionuclide transport in groundwater**
    - **Ion-exchange and absorption of radionuclides on DUO_x**
    - **Filter radioactive colloids from groundwater**

DUO_2 Reduces Radionuclide Releases By Reacting With Oxygen

- **SNF and SNF UO_2 are stable under chemically reducing conditions**
- **DUO_2 reacts with oxygen to yield $(DU)_3O_8$ and DUO_3*xH_2O; oxygen removal creates chemically reducing conditions**
- **DUO_2 reacts before SNF UO_2**
  - **DUO_2 outside the SNF**
  - **DUO_2 is a high-surface area particulate**
  - **SNF UO_2 is protected by clad**

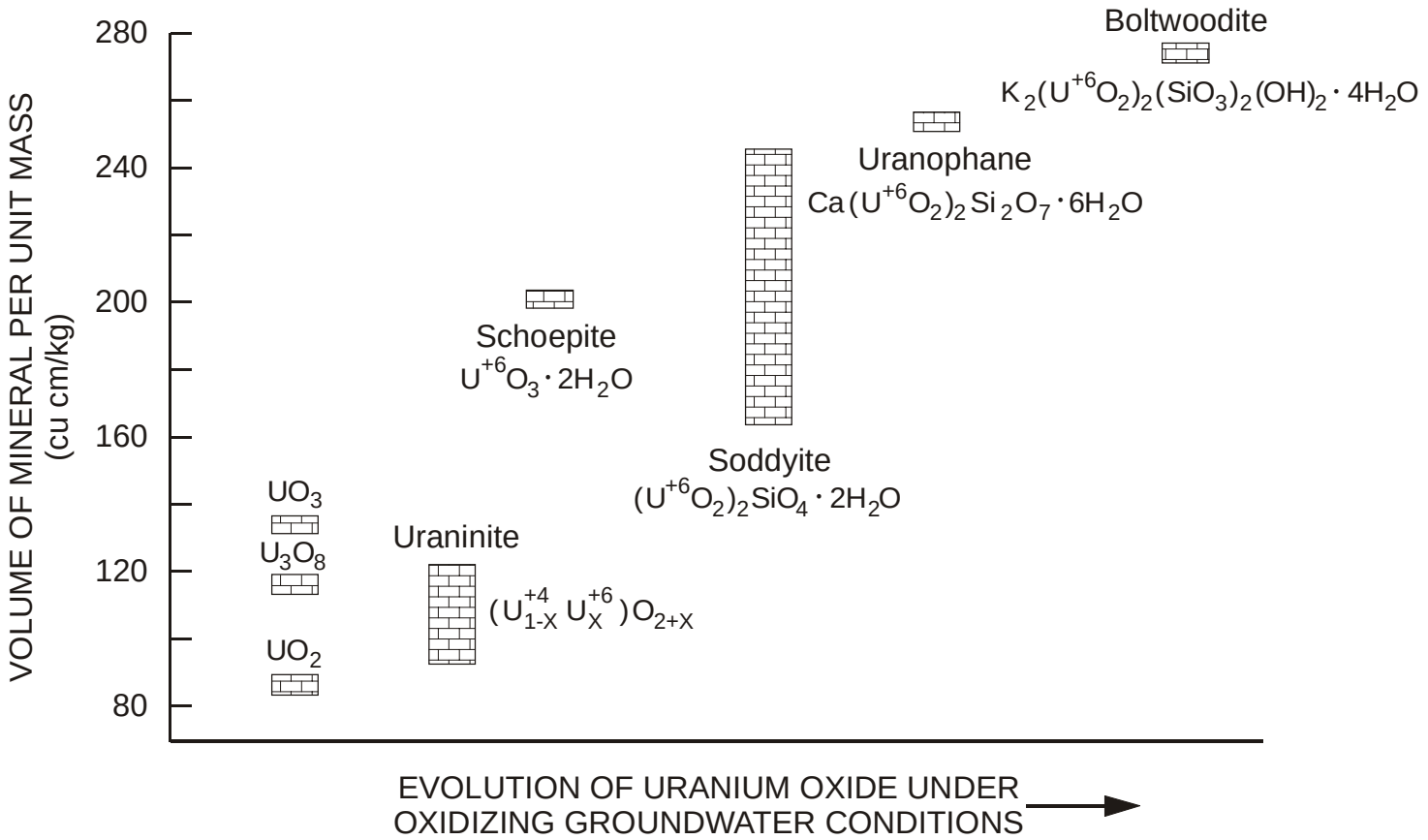
Depleted Uranium Oxides In The 4+ Valence State Help Maintain Chemically Reducing Groundwater (With Low SNF Uranium Solubility) In The Waste Package



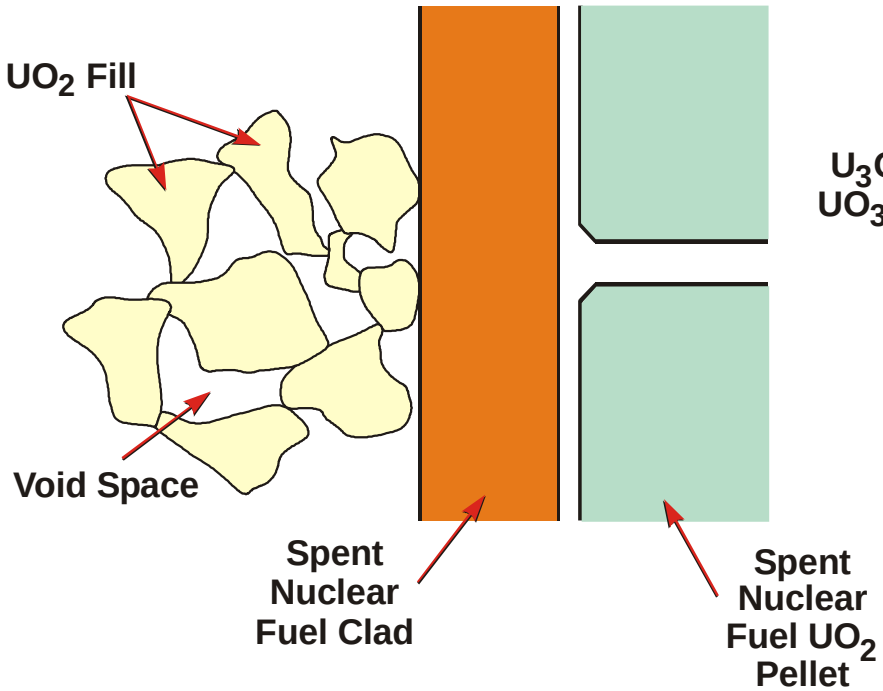
DUO_2 Reduces Air And Groundwater Flow Through WP

- **DUO_2 is oxidized to U_3O_8 and UO_3*xH_20**
- **Oxidation products are >30% larger**
  - **Swelling fills void spaces in WP**
  - **Fluid flow through the WP is reduced**
    - **Oxygen diffusion slowed with slower oxidation**
    - **Groundwater flow slowed with reduced radionuclide transport from the WP**

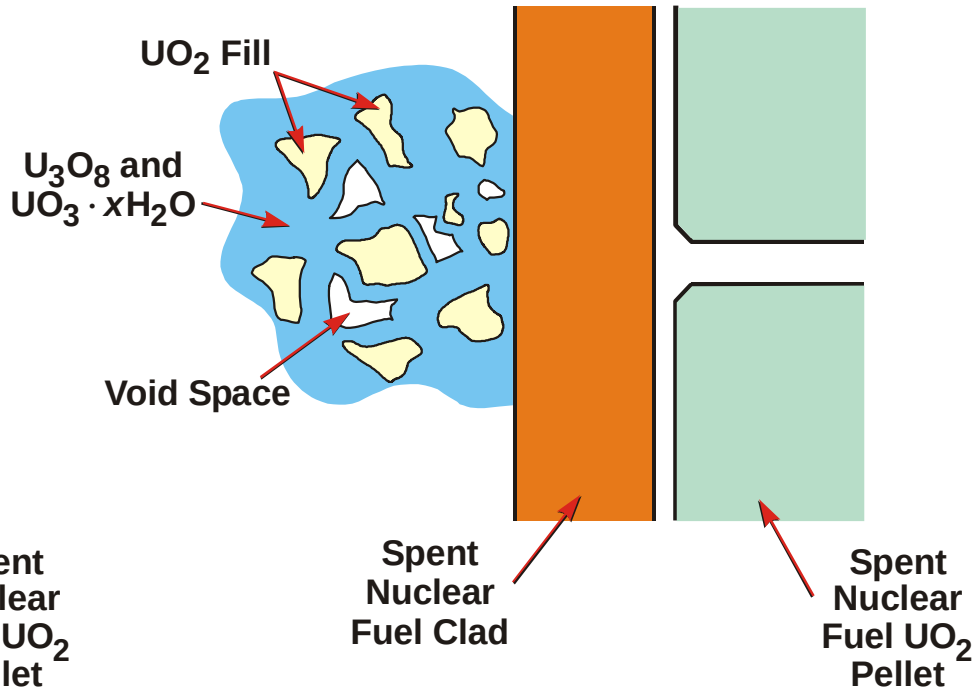
Volume Of The Uranium Mineral Versus Evolution Of Uranium Oxides Over Time To Hydrated Uranium Silicates



Initial Conditions



Conversion of UO_2 to Higher Oxides



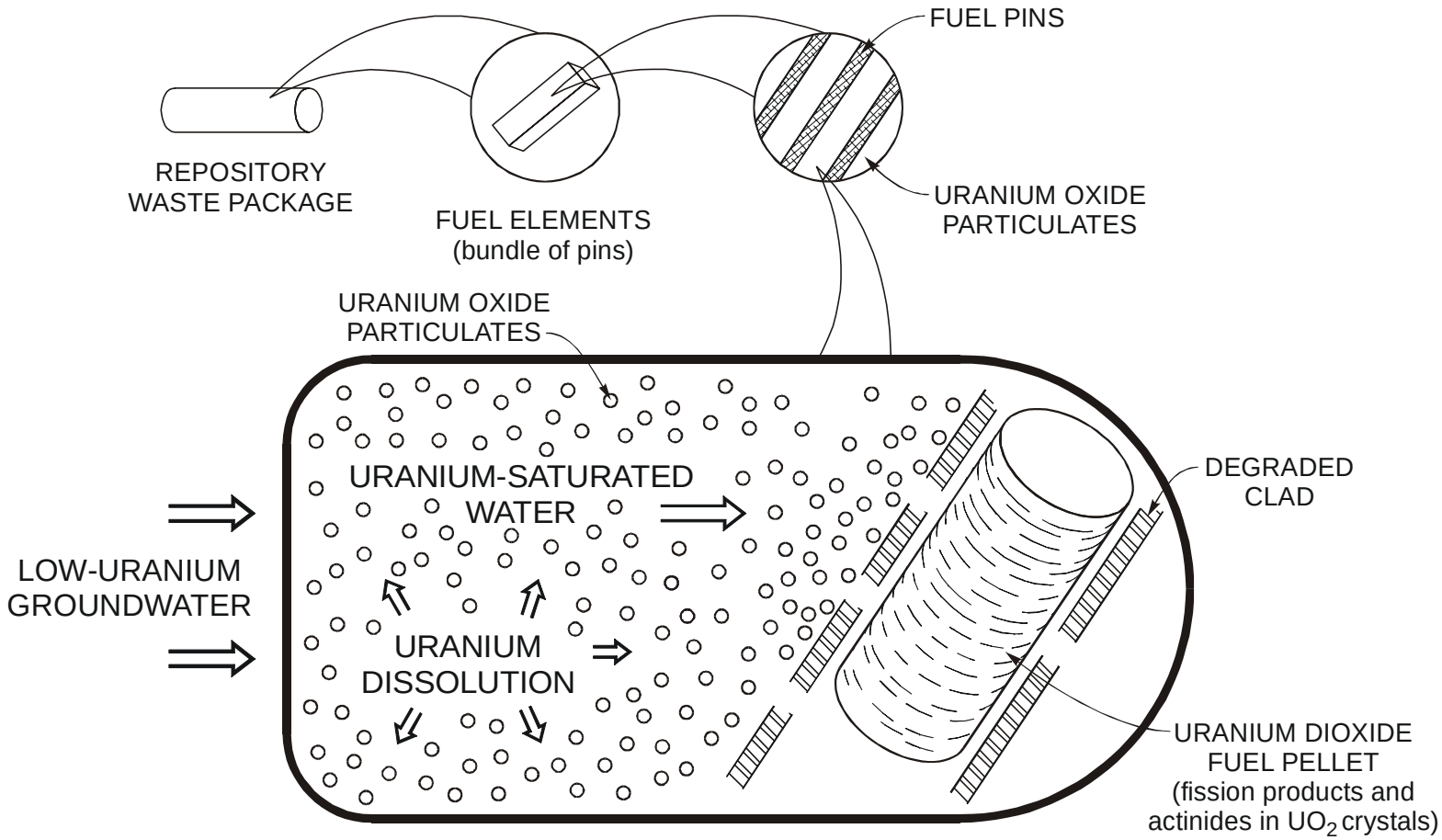
DUO_2 Reduces Radionuclide Releases By Slowing Radionuclide Transport In Groundwater

- **Adsorption and ion exchange**
  - **UO_2 oxidation products absorb and ion-exchange with many radionuclides**
  - **Delays radionuclide transport in groundwater**
- **Filtration**
  - **Many radionuclides (particularly actinides) form colloids (small particulates transported by groundwater)**
  - **DUO_2 oxidation products act as filters**

DUO_2 Reduces SNF UO_2 Dissolution Rates By Saturating Groundwater With Uranium

- **DUO_2 saturates groundwater coming into the WP with uranium**
- **Uranium-saturated groundwater can not dissolve SNF uranium**
- **SNF radionuclide releases are slowed.**

Depleted Uranium Fill Saturates Waste Package Groundwater With Uranium And Thus Minimizes SNF Uranium Dioxide Dissolution



Relative Fill And Cermet Comparisons

- **Fill strengths (direct contact between SNF and DUO_2)**
  - **Minimize radionuclide releases from the WP**
  - **Minimize uncertainties with criticality analysis**
- **Cermet strengths**
  - **Predictable radiation-shielding material (no potential for settling and no voids)**
  - **Minimize operational impacts (DUO_2 is invisible—embedded in the steel)**

Technology For UO_2 Particulate Fill Addition To WPs Currently Exists

- **The U.S. conducted experiments with iron shot that filled dummy PWR assemblies**
  - **Iron density: 7.86 g/cm^3**
  - **UO_2 density: 10.96 g/cm^3 (theoretical)**
- **Canada conducted multiple, full-scale WP fill tests (but not using DUO_2)**
  - **Technology tested on multiple fill types**
  - **Spaces between fuel pins in CANDU SNF are smaller than those in LWR SNF**