Repository Applications for Depleted Uranium (DU)
(Potential Use of the Entire DU Inventory)

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DU Uses R&D Program Review
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Outline

- Overview
- DU use in repository applications
- DU use in multipurpose casks
- Economics
- Past and future plans
- Conclusions

Overview

Task Objectives

The task objectives are to identify, develop, assess, and encourage beneficial uses of DU for repository applications

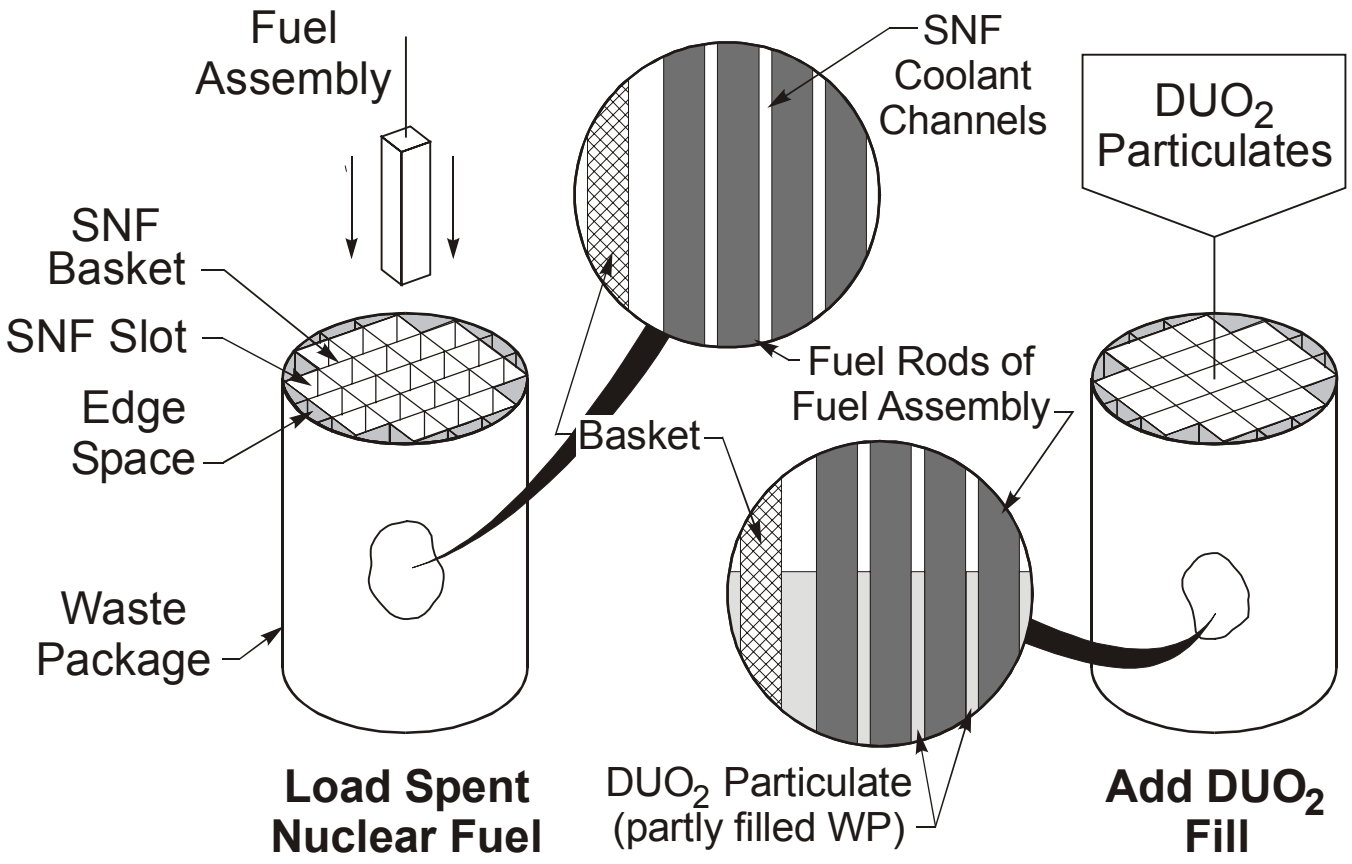
Task Justification

- Potential to beneficially use the entire DU inventory
  - Fill material (Yucca Mountain Project [YMP] and Waste Isolation Pilot Plant [WIPP])
  - Package material of construction (cermet)
    - Multipurpose casks (storage, transport, and disposal)
    - YMP waste packages (WP)
    - WIPP WPs
- Potential significant repository benefits
  - Criticality control
  - Reduced radionuclide release rate from the repository
  - Shielding
- Minimal regulatory and public acceptance issues
  - DU used in a nuclear application
  - Meets regulatory requirements (DOE, NRC, EPA, etc.)

Depleted Uranium Dioxide (DUO_2) Is the Preferred Form of DU

- 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

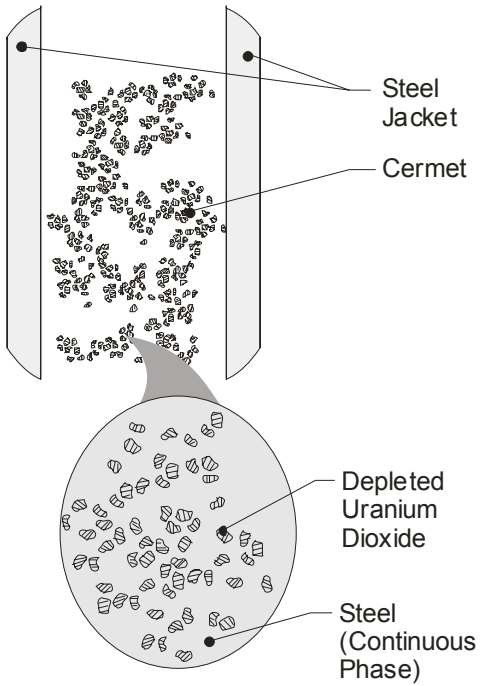
DUO_2 Particulate Fill Can Be Added to SNF Waste Packages (3-4 kg DU/kg SNF)



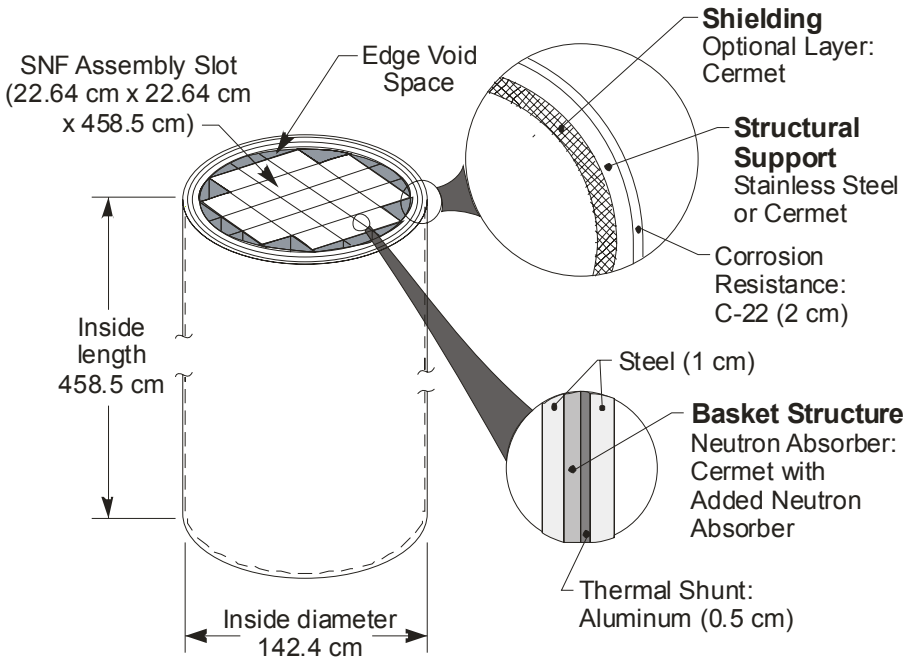
Storage, Transport, and Repository Applications: Casks Can Be Constructed of a DUO_2-Steel Cermet: 3-8 kg DU/kg SNF

(Cemet Manufacturing Demonstrated: Cermets Were Used as Fuels in Some Reactors)

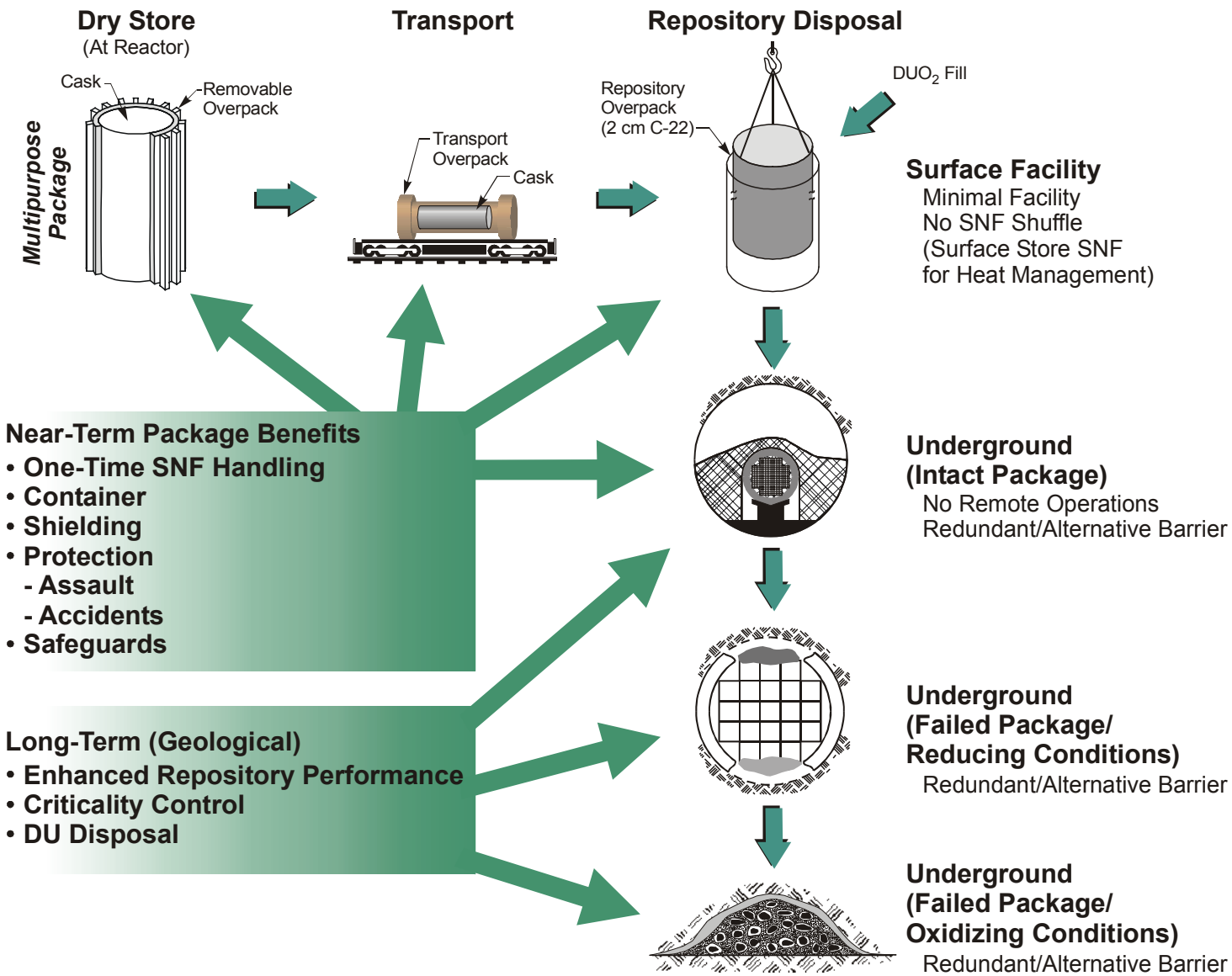
Cermet



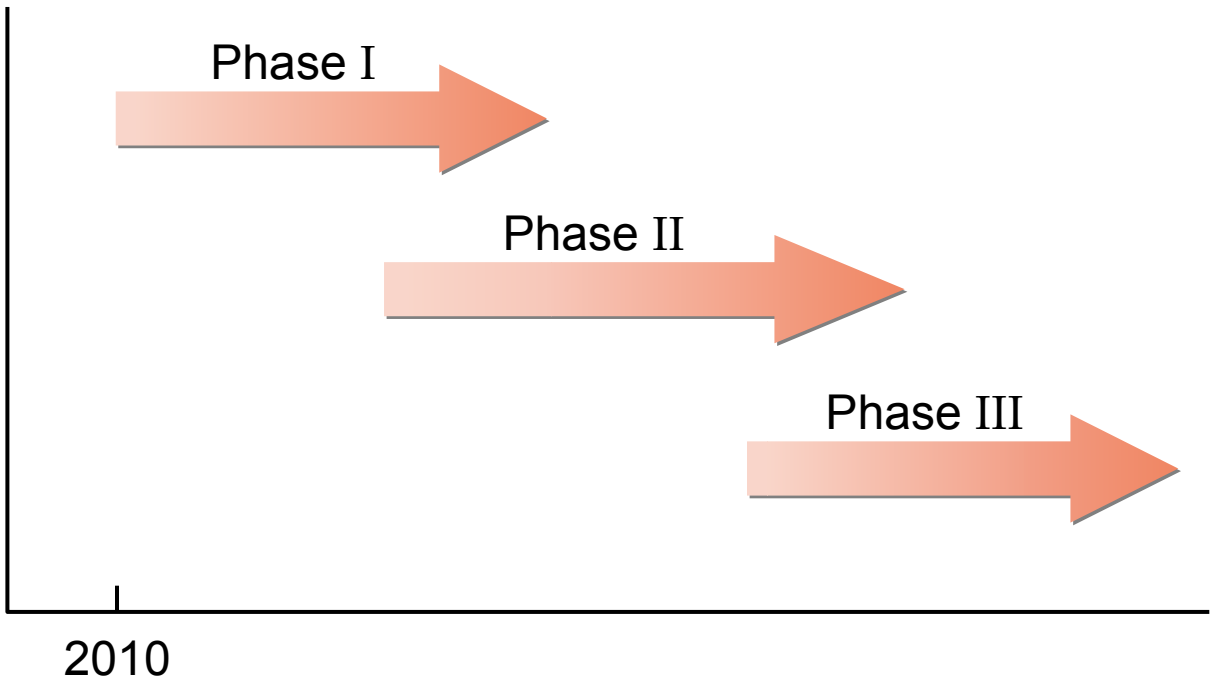
Applications



Repository System Applications And Benefits Of DU



The Repository Will Be Developed in Phases with Multiple Introduction Times for New Technologies



DU Use in Repository Applications

Engineering feasibility

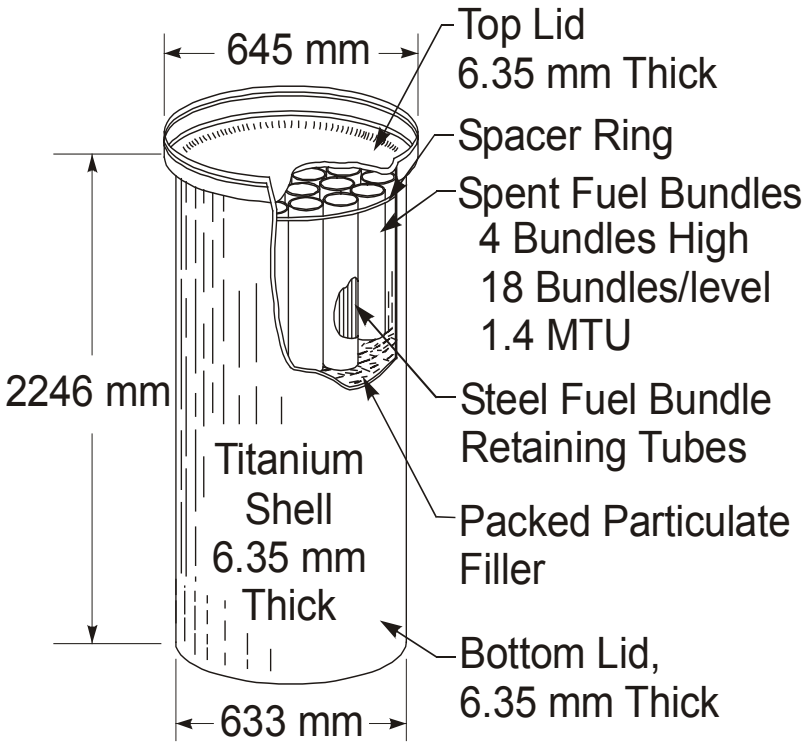
Impacts of DUO_2 on repository performance

- Stage 1: Intact WP
- Stage 2: Failed WP (Reducing conditions)
- Stage 3: Failed WP (Oxidizing conditions)

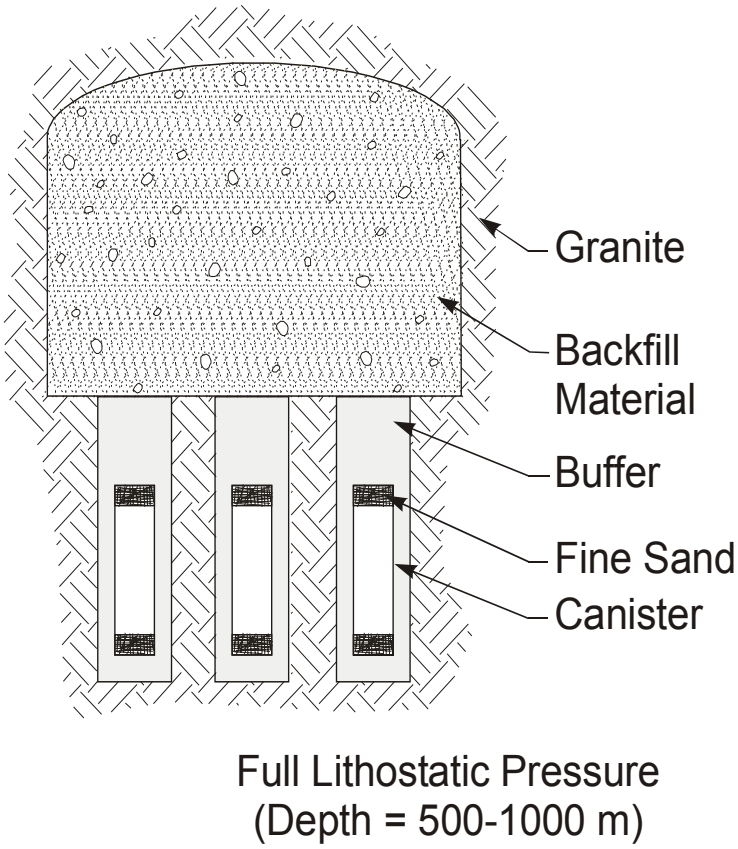
Fill Feasibility: Large-Scale Canadian Experiments Demonstrated Fill Technology

- Canada developed a thin-wall titanium WP
  - Outstanding corrosion resistance
  - Expensive material: use thin-wall WP to limit quantities
  - Fill to be added to support WP against crushing
- Investigated many fills
  - DUO_2 not investigated because it was not available (no DU in Canada)
  - Filling and emptying technology investigated
- Full-scale successful WP testing with fill

Canadian Thin-Wall (0.635-cm) WP for CANDU SNF

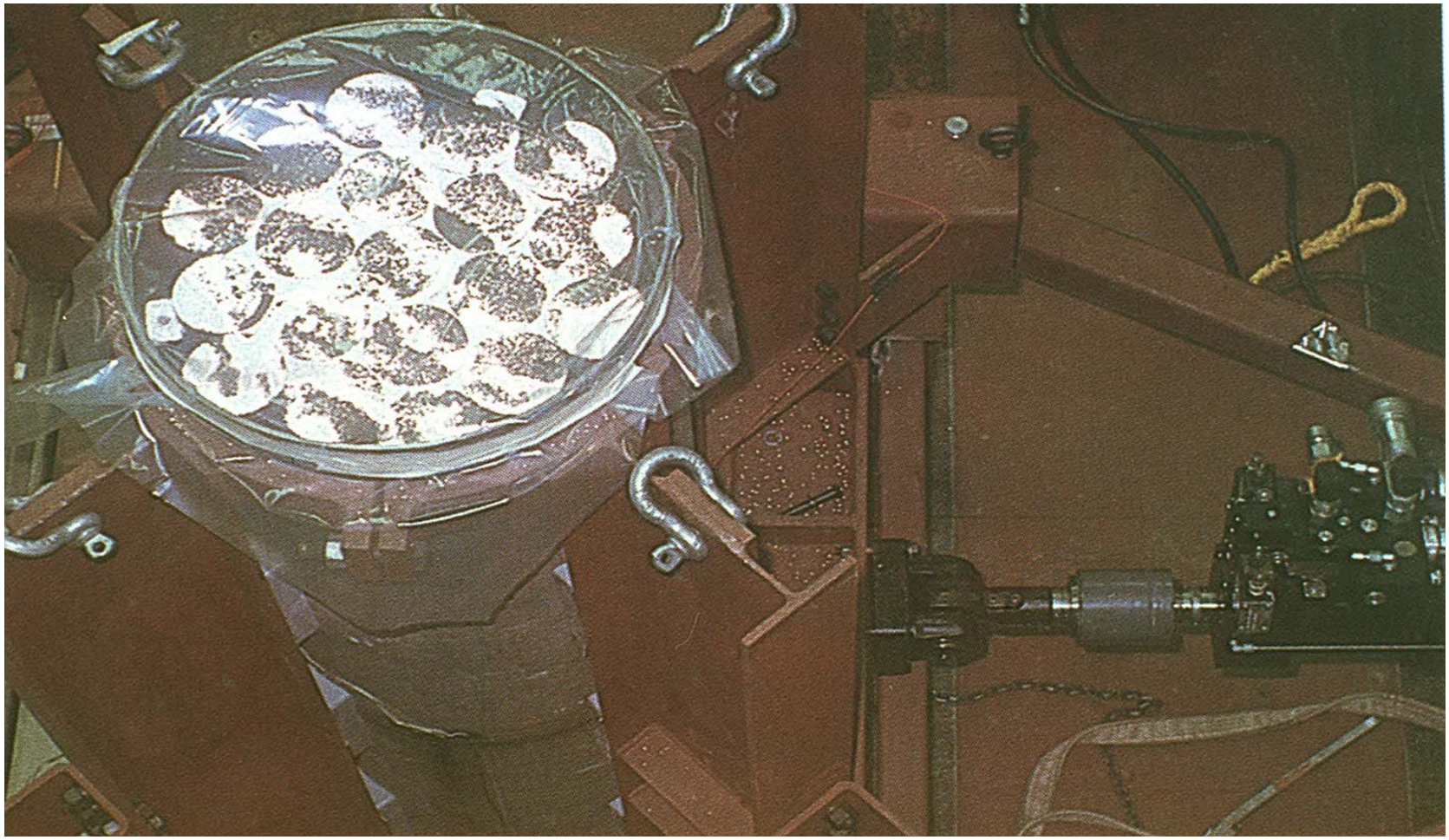


Canister Concept



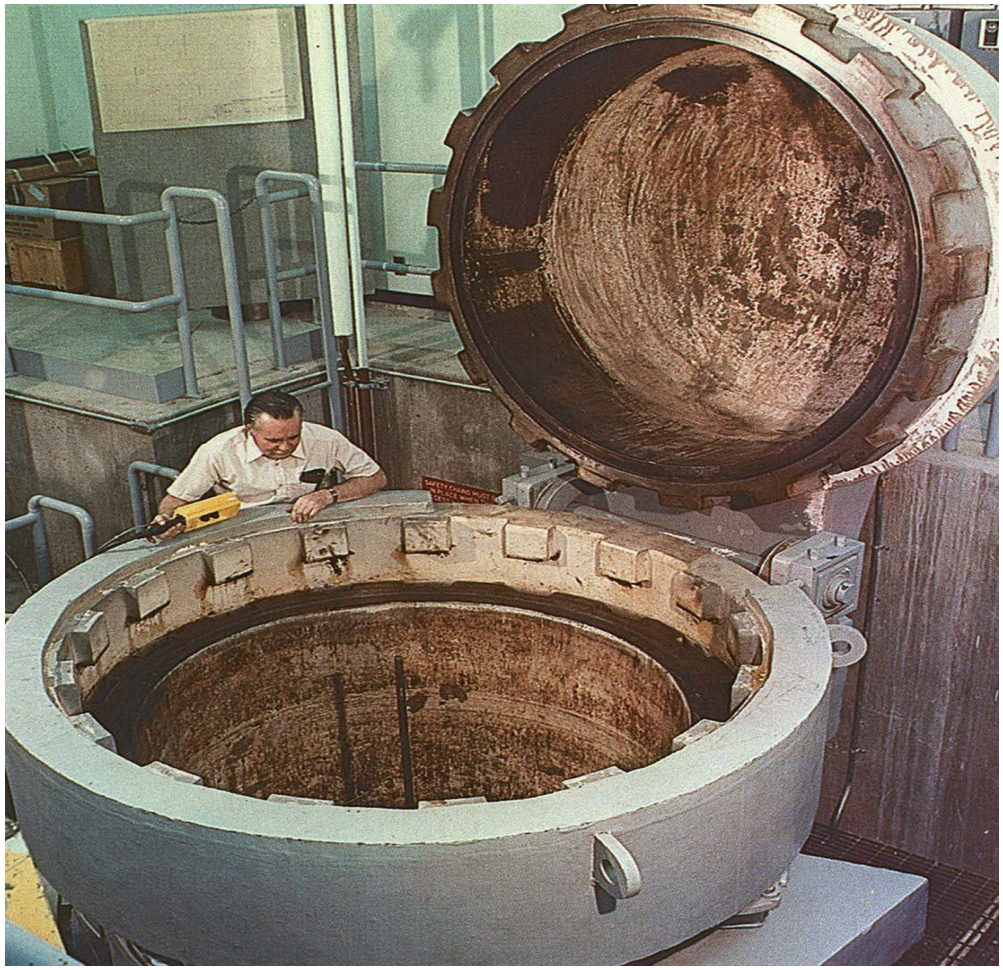
Repository Disposal Concept

Canadian WP with Fill and Dummy SNF
(Courtesy of AECL)



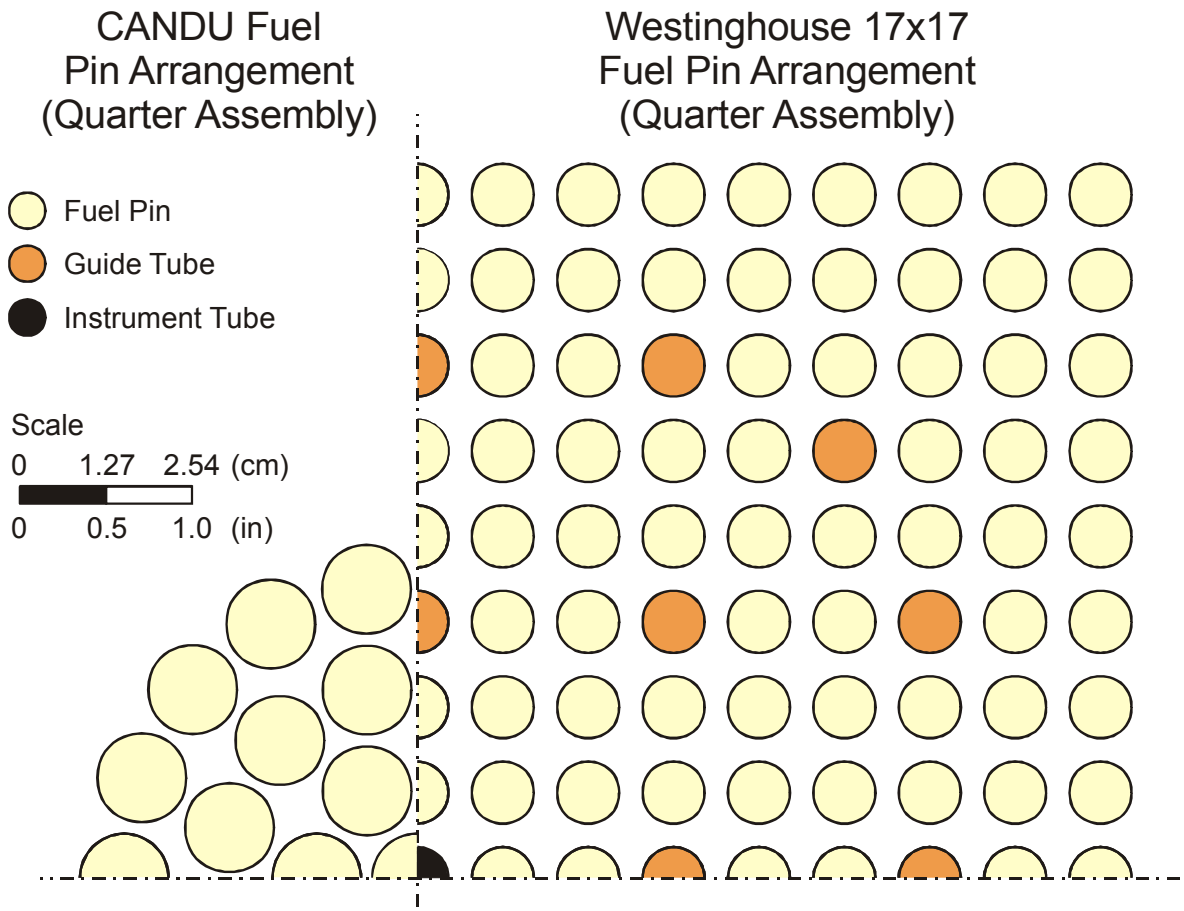
WP Hydrostatic Tests (10 MPa and 150°C) Proved Fill Supported WP External Walls

(Courtesy of AECL)



Particulate Filling of LWR SNF Is Expected To Be Easier Than with CANDU SNF

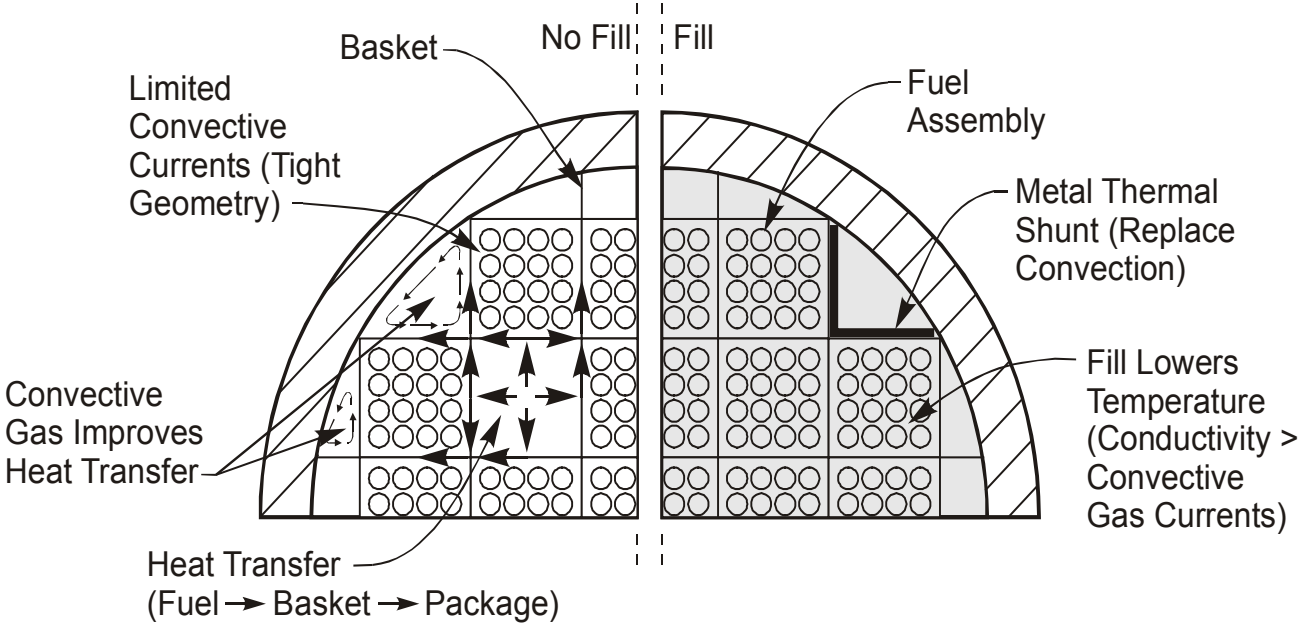
(Smaller Gap Dimensions with CANDU SNF)



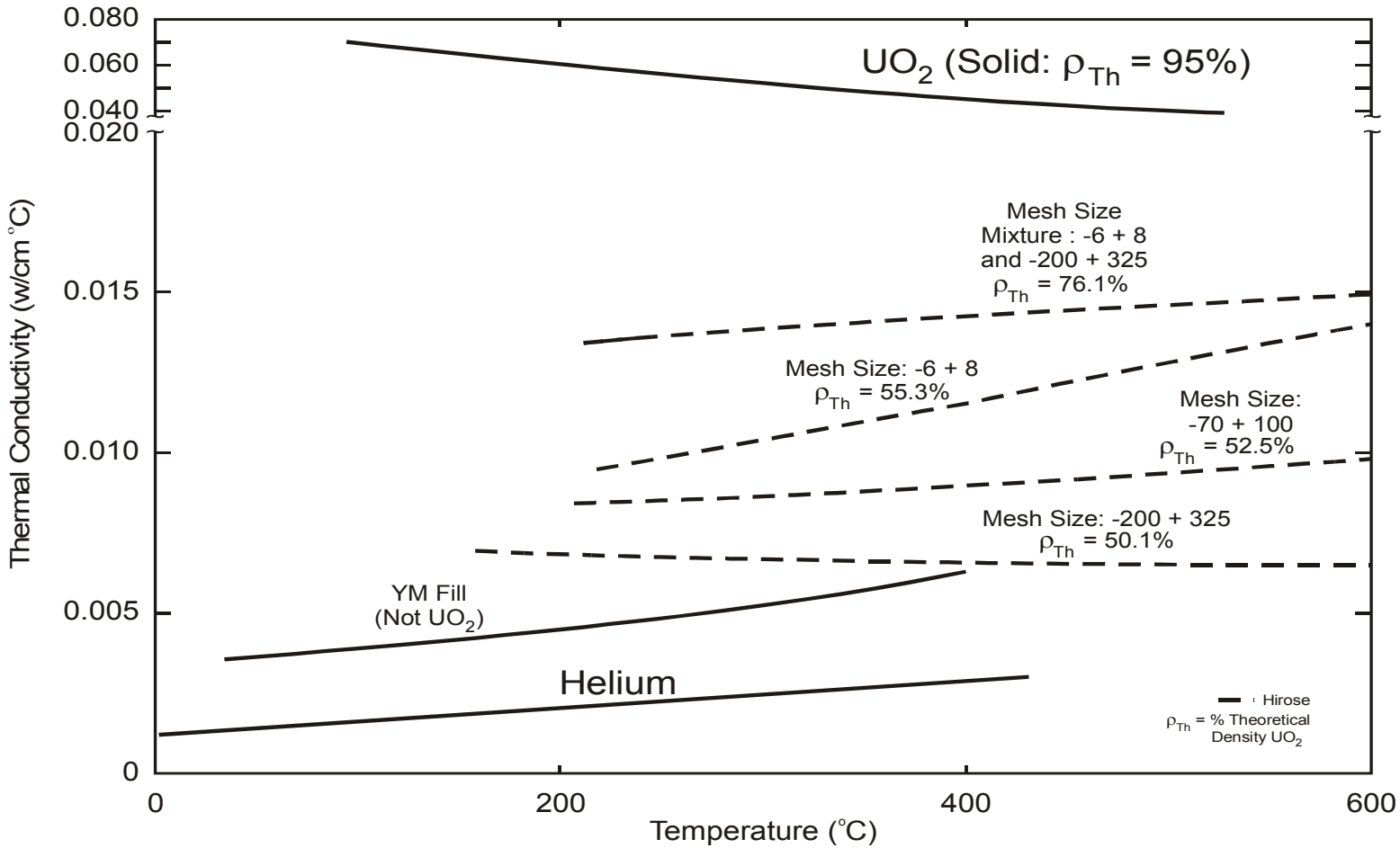
The United States Successful Conducted Steel-Shot Fill Experiments with LWR Dummy Fuel

Fill Engineering Feasibility: DUO_2 Fill Lowers SNF Temperatures When Geometric Dimensions Are Small

(Fill Conductivity Is Greater Than That of Helium)

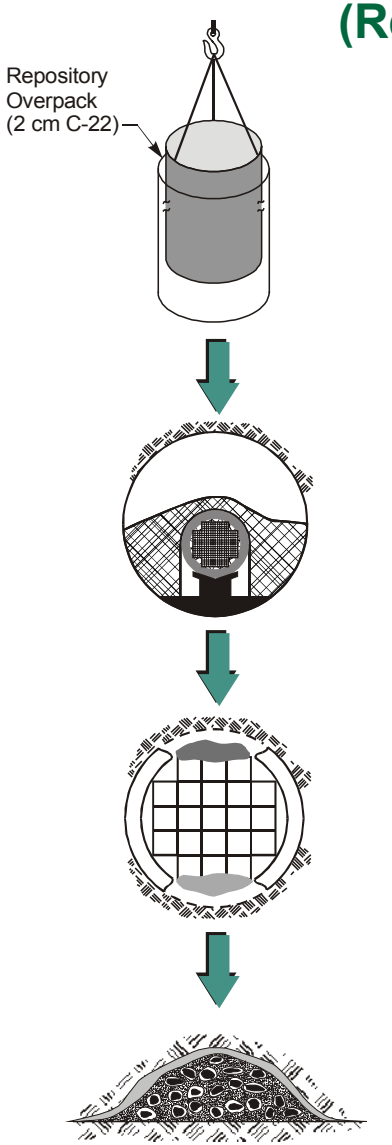


Measured Thermal Conductivity for Uranium Dioxide Particulate Fill in Helium (1 atm)



Performance Depends Upon WP Evolution Over Time

(Relevant Studies Identified)



Surface Facilities

- Cermet Shielding Capabilities (September 2001)
- Status of Fill Technology (October 1997)
- Limits to Fill Fraction (September 2000)

Underground (Intact Package)

- Fill Impacts on Temperature (April 2001)

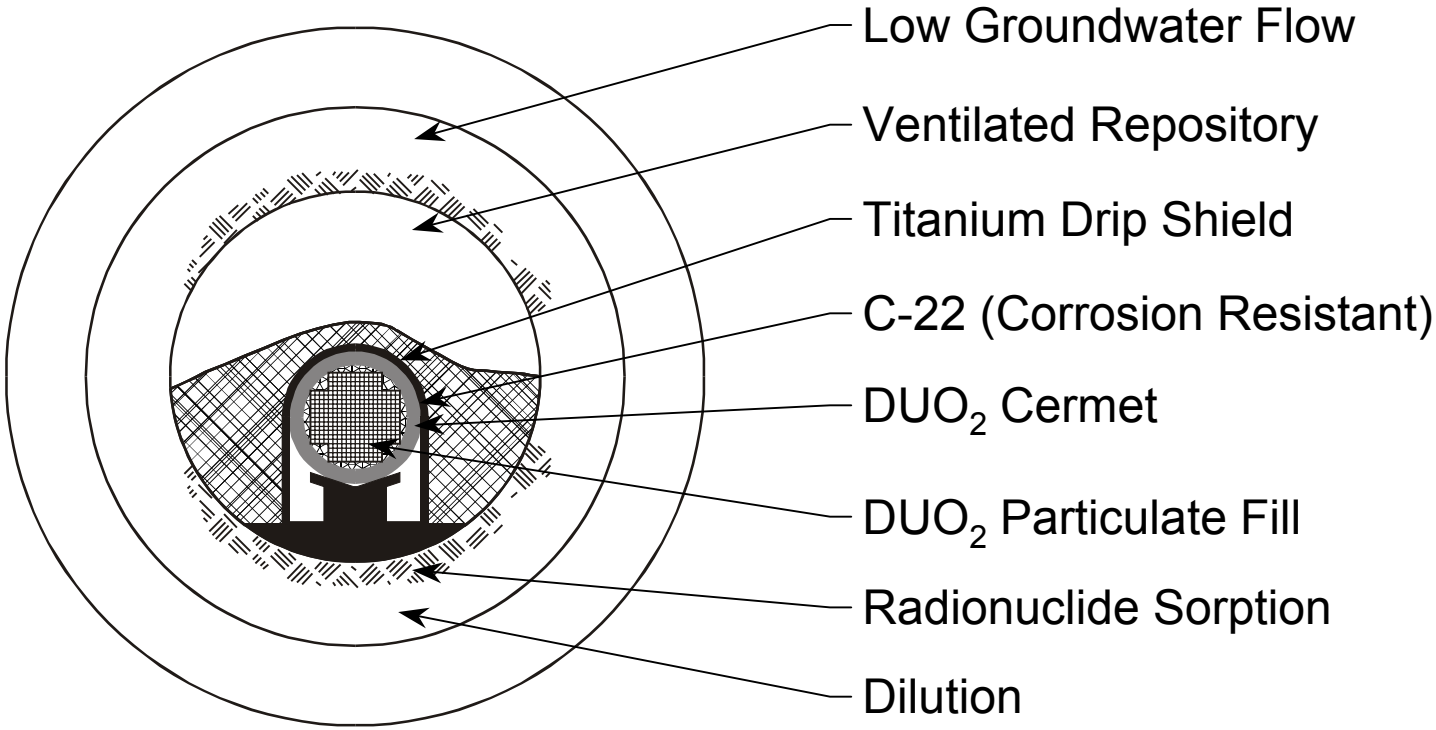
Underground (Failed Packages: Reducing Conditions)

- Time Reducing Conditions Maintained (November 2001)
- Impacts of Oxidative Radiolysis (Sweden: SKB)

Underground (Failed Packages: Oxidizing Conditions)

- Assured Criticality Control Strategy
  - Fill (September 1997; September 2000)
  - Cermet (November 2001)
- Expected Evolution (September 2000; February 2001)
- Radionuclide Sorption on Uranium Species (ANL; Russia)
- Non-Standard SNF (FY 2002)

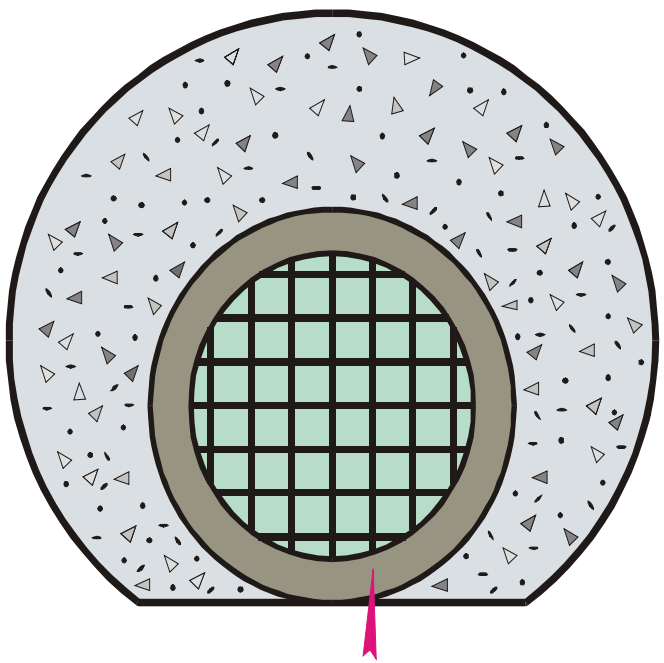
The $DU0_2$ Is an Independent Barrier to Radionuclide Release That Operates Sequentially with Other Barriers



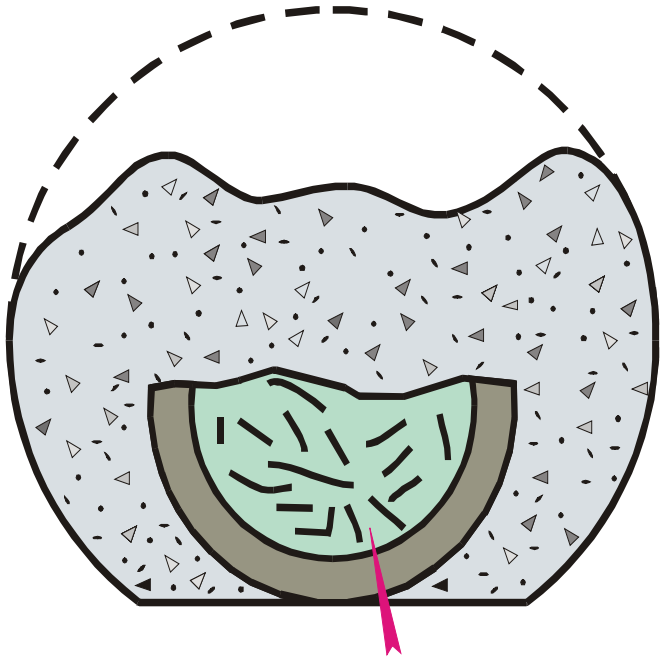
Stage I: Intact WP in Repository: Fill Can Delay WP Failure

- No migration of SNF radionuclides occurs until after the WP fails
- Fill can provide internal structural support to delay WP failure (more than one-half of the WP interior is empty space)
  - WP walls thin with time
  - Tunnel collapse stresses WP
- Canada demonstrated the capabilities of ductile WPs supported by fill

Intact WP: Fills Provide Internal Support That Delays WP Collapse with Loss of Barriers Against Groundwater Contact with SNF



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



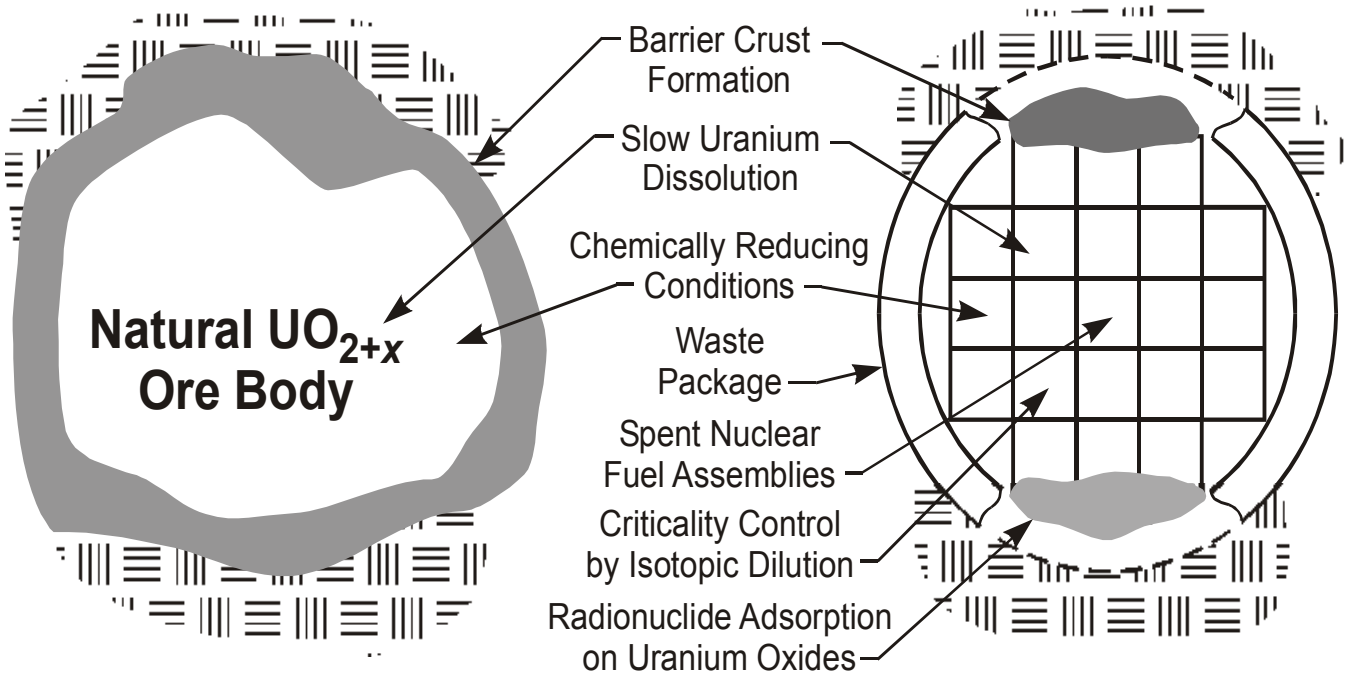
Failed Waste Package
(Collapse With No
Internal Support)

Stages 2 and 3: Failed WP in Repository: Multiple DUO_2 Mechanisms Exist To Delay Radionuclide Release

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

Some Uranium Ore Deposits Have Remained Intact for Millions of Years: The Same Mechanisms Should Protect SNF in Failed WPs Containing DUO_2

(DUO_2 Is The Only Sacrificial Compound to Preserve SNF UO_2 Under All Conditions)



In All Failed WP Scenarios, DU Partly or Fully Saturates Groundwater Within WP: This Slows SNF Uranium Dissolution

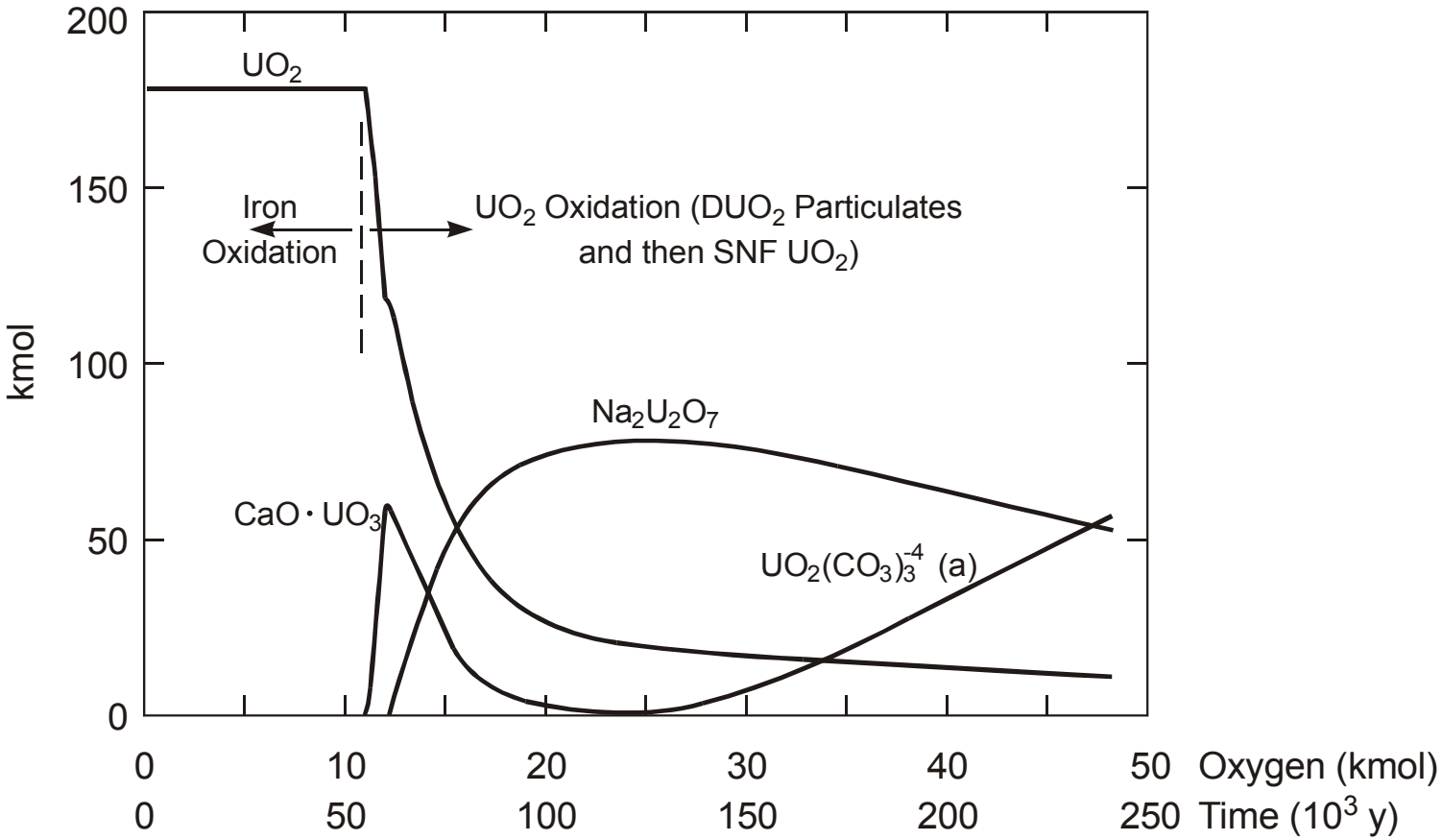
- SNF dissolution rate depends upon the uranium concentration gradient from the SNF uranium surface to groundwater
- Fully saturated DU groundwater can not dissolve more uranium
- Degree of saturation depends upon dissolution kinetics

Stage 2: Failed WP (Reducing Conditions): DUO_2 Maintains Chemically Reducing Conditions To Preserve SNF for Extended Times

- Iron and then DUO_2 react with oxygen in groundwater to maintain chemically reducing conditions within the failed WP
  - Iron forms Fe_3O_4, then soluble Fe carbonates
  - Uranium goes through multiple species
- SNF does not degrade under these conditions: most fission products and actinides are trapped in UO_2 crystals
- This delay is not in the current YM system

Idealized Cermet WP (No Fill) Calculations Show No SNF UO_2 Oxidation for 140,000 y

(ORNL Calculations, YM Groundwater Flow of 32.5 mm/y for 250,000 years with 475 kmol Fe and 143 kmol DUO_2 in Cermet)



Stage 3: Failed WP (Oxidizing Conditions): Oxidizing Groundwater Ultimately Degrades SNF and Releases Radionuclides

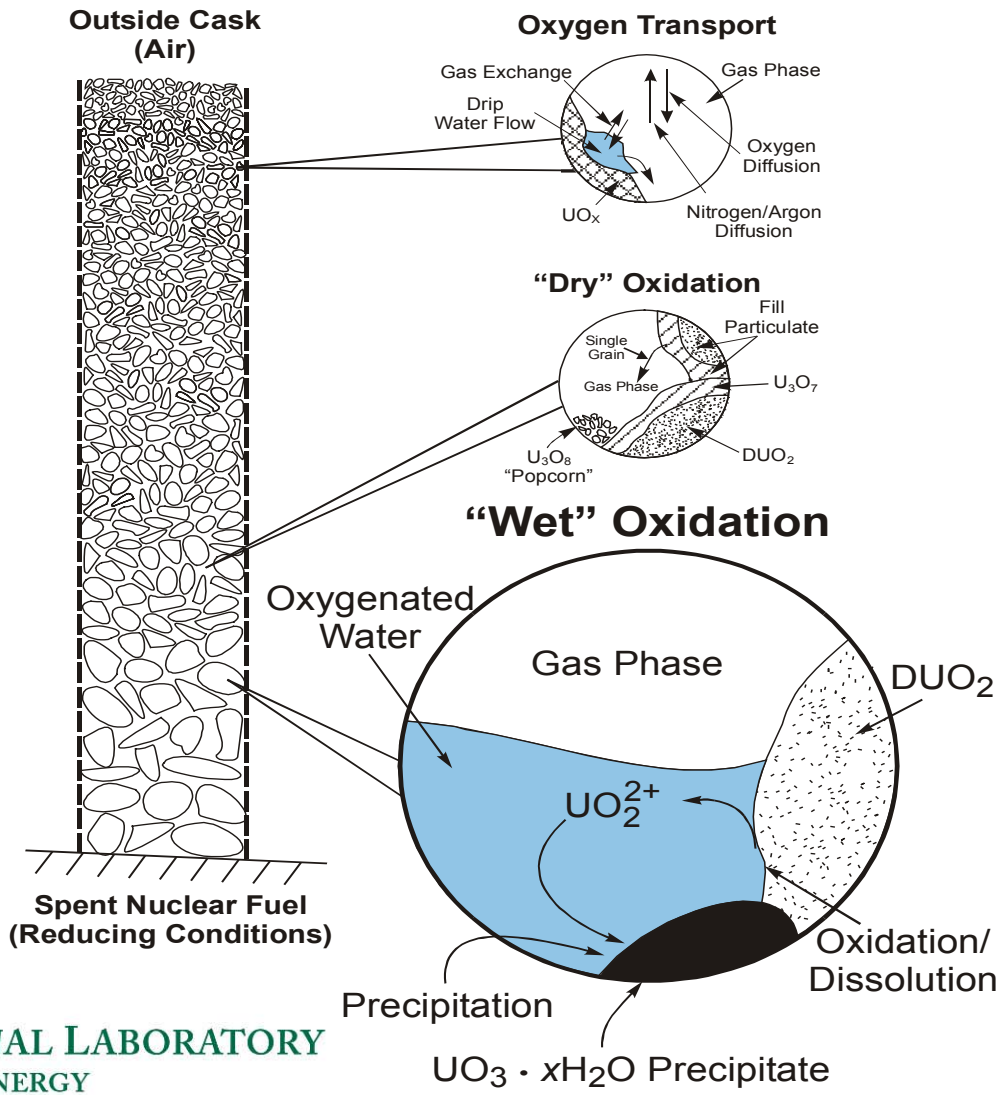
- Expected YM conditions
- Occurs after sufficient oxygen enters WP to create oxidizing conditions
- Multiple effects
  - Oxidation of DUO_2 increases volume with blocking of fluid flow paths (slows further oxidation and delays SNF degradation)
  - Sorption of fission products and neptunium on uranium oxides and silicates
  - Isotopic mixing of uranium isotopes

DUO_2 Geochemistry Is Expected to Slow Gas and Groundwater Flow in WP

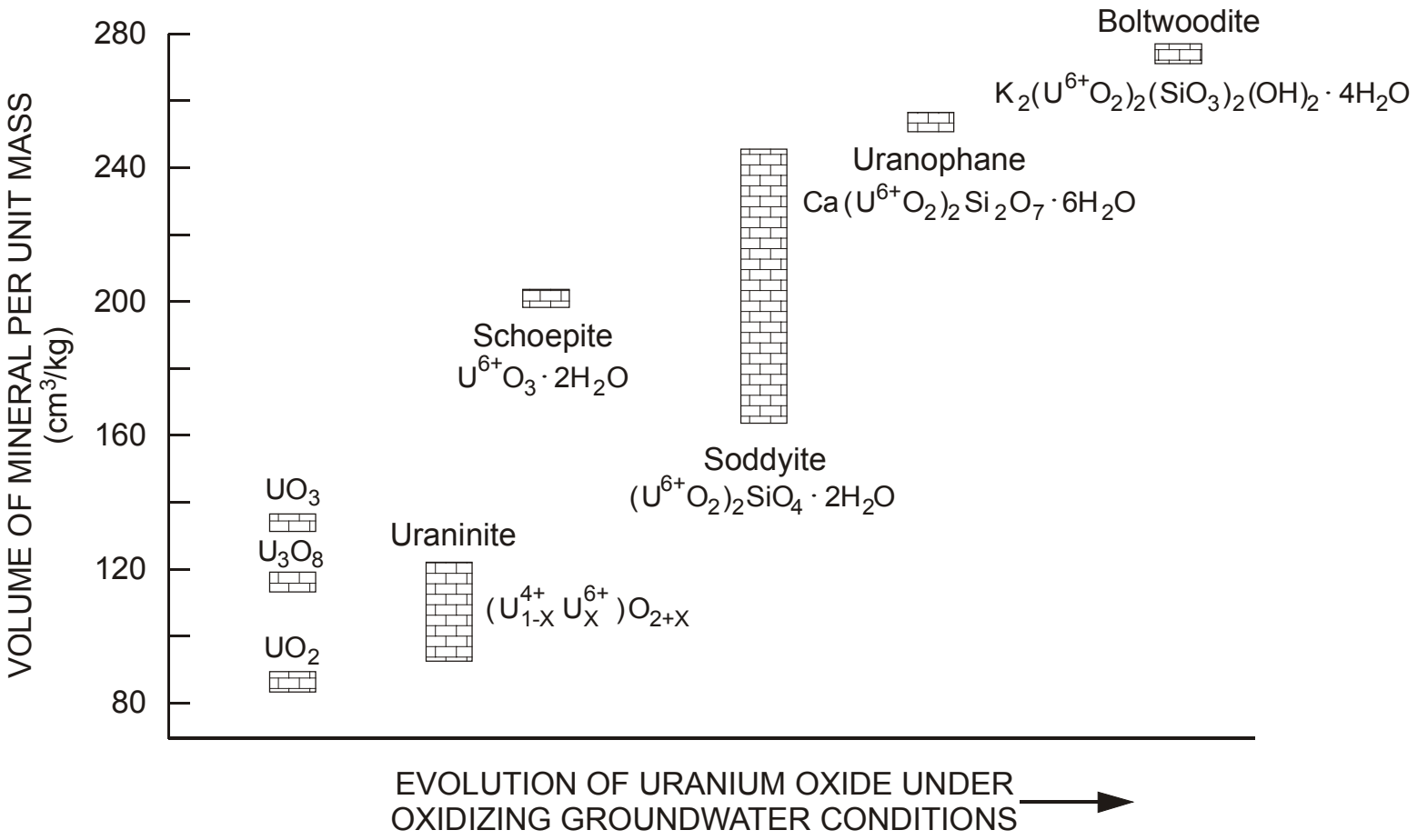
- DUO_2 oxidation occurs by two mechanisms
  - Dry oxidation (early WP failure)
  - Wet oxidation (late WP failure)
- DUO_2 is ultimately converted to uranium silicates (thermodynamically stable form)
- Higher volume oxidation products block flow paths for fluids (water and gases)
- WP degradation (oxidation) slows with partly blocked fluid flow paths

DU Wet Oxidation Slows SNF Degradation

(Oxidation Is a Multistep Process: Oxidation, Dissolution, and Precipitation with a Volume Increase To Block Further Oxygen and Water Transport)



Evolution of Uranium Oxides over Time to Hydrated Uranium Silicates Tends To Block Air and Groundwater Flow



Hydrated DU Oxidation Products Will Delay SNF Radionuclide Releases

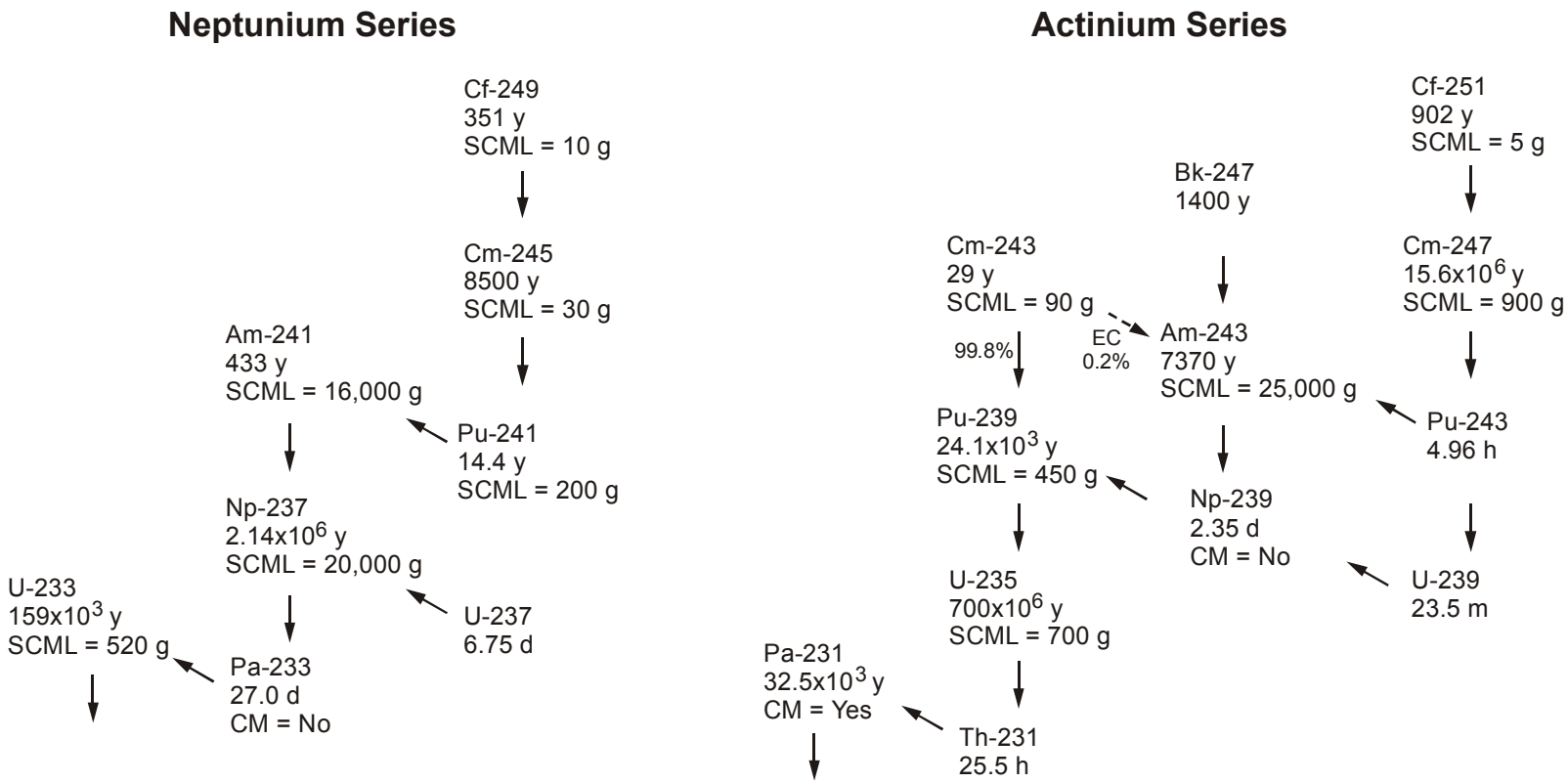
- Heavy metal hydrated oxides sorb and ion-exchange with many radionuclides
- Limited data on hydrated uranium oxides show this effect
  - Dissolution/co-precipitation of U species (ANL)
  - Sorption (proposed Russian activity)
- Significant uncertainty associated with the radionuclides of greatest interest (Np and Tc) that control repository performance

DU Provides An Alternative Criticality Control Strategy
(DOE SNF, Navy SNF, High-Fissile Assay Wastes)

- Many viable criticality control strategies
  - Fissile mass limits
  - Geometry
  - Isotopic dilution (DU)
- DU isotopic dilution option
  - Method responsible for avoiding nuclear criticality in the natural environment
  - Freedom of design

Criticality Control: Half-Lives and Geochemistry Imply That Repository Criticality Is Controlled by $^{235}U/^{233}U$

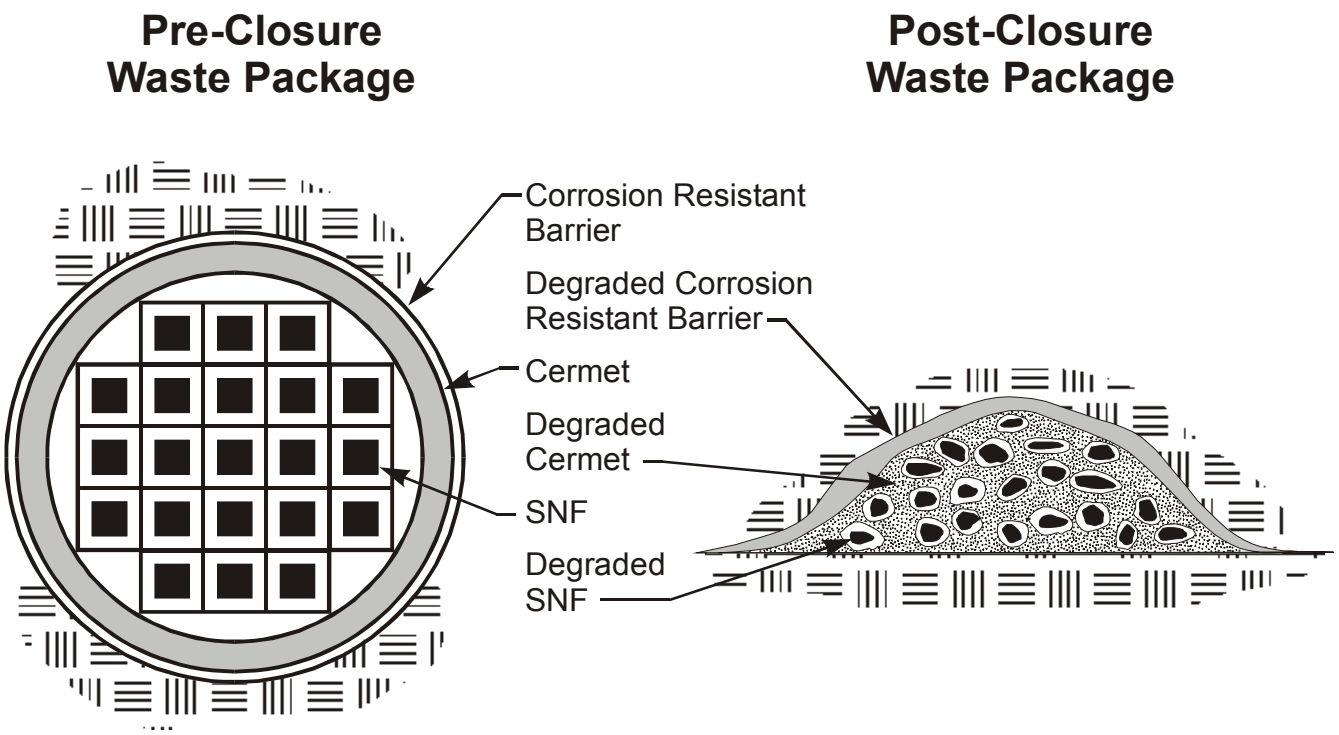
(Fissile Actinides [^{239}Pu, etc.] Decay to Uranium Isotopes Before Transport)



The Criticality Control Strategy Is To Overwhelm the Potential for $^{235}U/^{233}U$ Criticality by Using DU

- Large quantities of DU in the WP
  - Cermet: 3+ tons of DU per ton of SNF
  - Fill: 3+ tons of DU per ton of SNF
- Average WP enrichment: <<1%
- Quantity of DU can be varied

Degradation over Time Will Physically Mix and Then Isotopically Mix DU with SNF and HLW Uranium Isotopes



Repository Disposal of DU

- Repository options may consume the existing and future inventory
- Disposal option acceptable
  - Meets NRC requirements
  - Meets YMP performance requirements
- Strategic disposal option (SNF and DU co-located)

DU Use In Multipurpose Casks

System Description

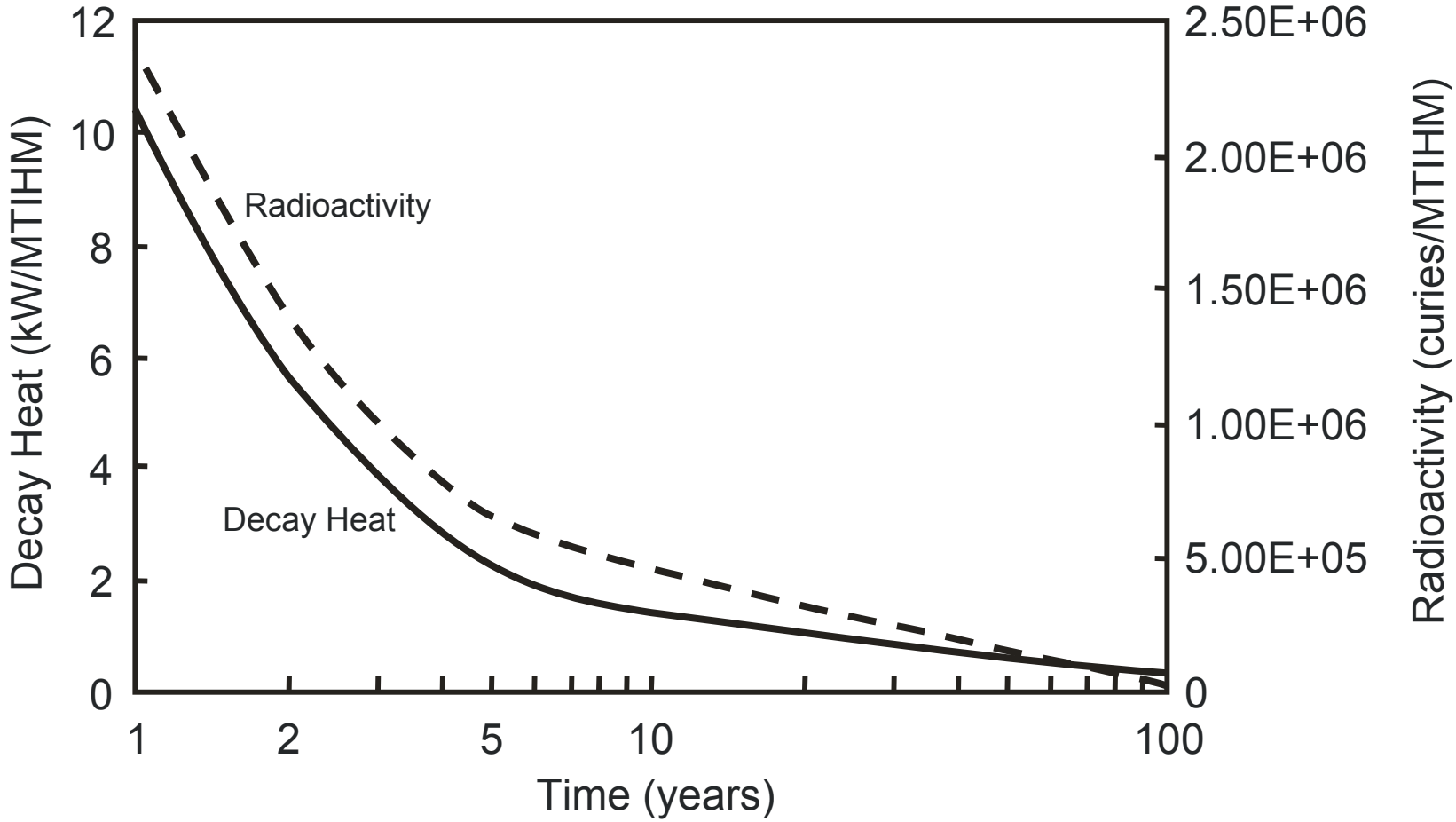
Incentives For Use of Multipurpose Cask

Incentives For *Cermet* Multipurpose Casks

(Excluding Repository Benefits)

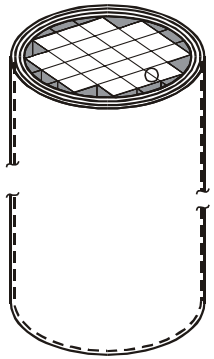
Issues Regarding Multipurpose Casks

System Issue: Multipurpose Storage, Transport, and Disposal Casks Must Handle SNF with Variable Characteristics



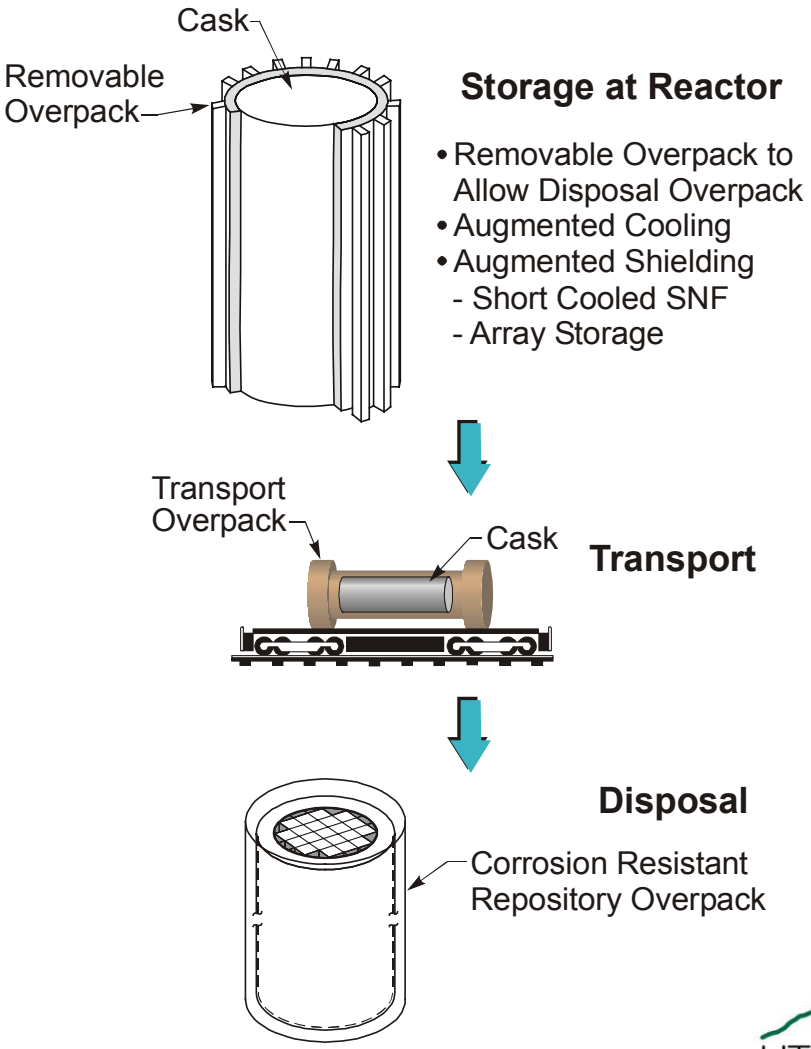
Multipurpose Cask Systems Use Overpacks To Address Variable Requirements

Multipurpose Cask



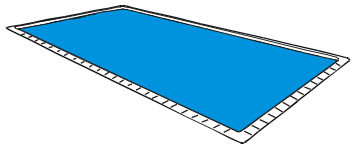
- Radiation Shielding
- Accident/Assault Protection: Multilayer Cermet
- Safeguards and Theft Resistance
- Decay Heat Removal

Multipurpose Cask System



Incentives: Terrorist Events May Result in Adoption Of Modified German Multipurpose SNF Cask System By the United States

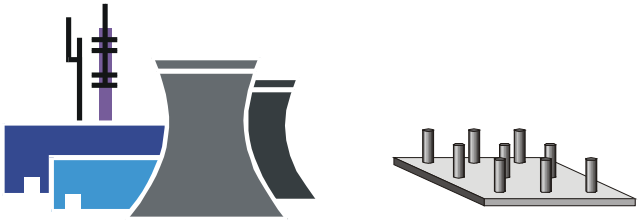
United States



Storage Pond

- Aircraft/assault not credible
- Pool storage outside containment
- Low SNF handling cost
- Some dry storage

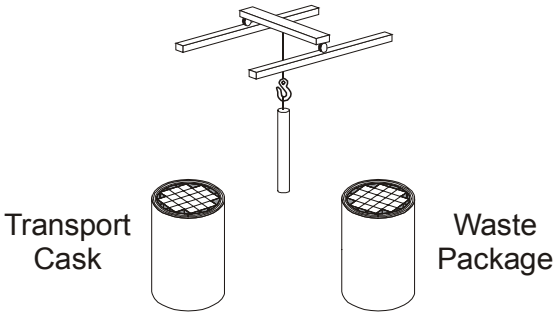
Germany



- Aircraft/assault credible
- Small pool in containment
- SNF handling in containment
- Multipurpose dry cask storage for all SNF

Incentives: Multipurpose Casks Reduce Repository Surface Operations, Risks, and Costs

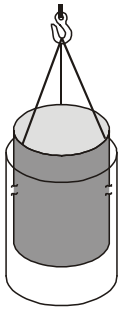
Current System



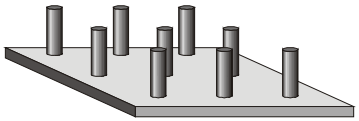
Remote Transfer of SNF

Adjusting Waste Package Heat Load for the Repository

Multipurpose Cask System



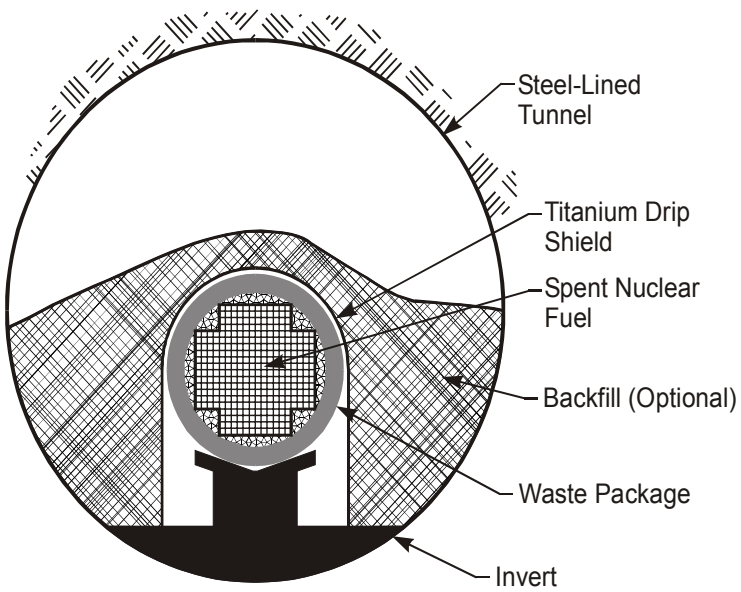
Addition of Overpack



Surface Storage Until Repository Acceptable Heat Load

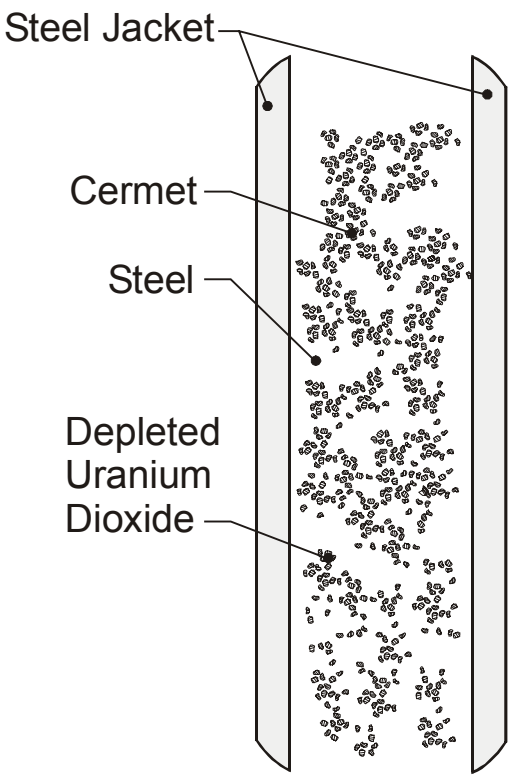
Incentives: Multipurpose Shielded Casks Simplify Underground Operations

(WP Placement, Inspection, Maintenance, and Backfill)



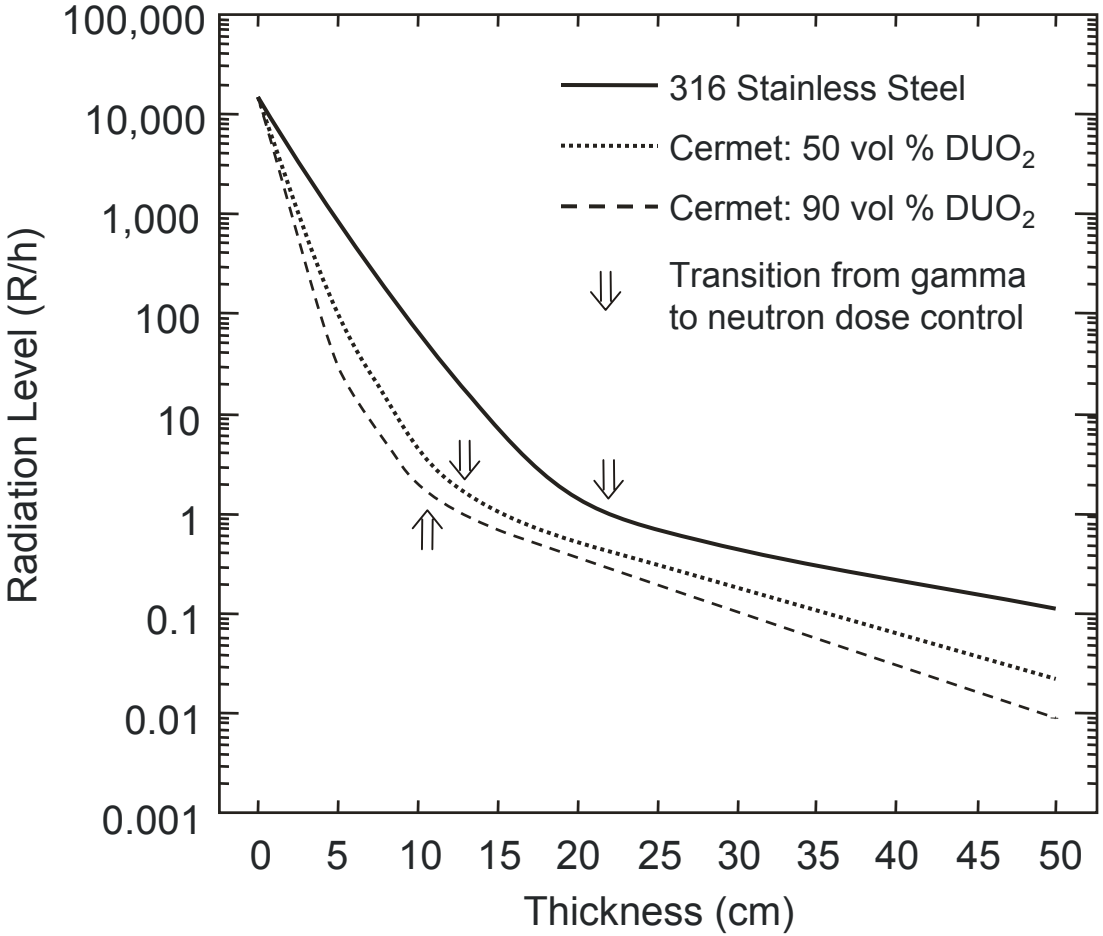
- **Cold repository option**
  - Ventilated repository lowers temperature; may reduce need for titanium drip-shield
  - Open repository with maintenance for 100+ years
  - Shielding simplifies maintenance
- **Simplify backfill placement**
  - Richards barrier
  - Fill to limit volcanic consequences

Cermet Benefit: Cermets Are Good Shielding Materials with Some Unique Capabilities



- Gamma Shielding Better Than Steel
  - Steel: 7.86 g/cm^3
  - DUO_2: 10.9 g/cm^3
- Neutron Shielding
  - High-density oxygen (DUO_2) moderator
  - Other neutron absorbers can be added
- Good Physical Properties
  - High thermal conductivity
  - No organics (no fire; acceptable to repository)

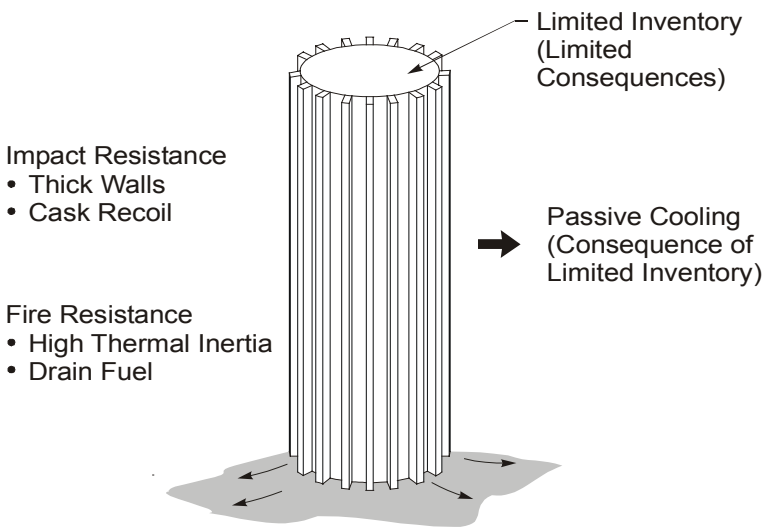
Shielding Effectiveness (R/h) of Different Materials
(Source Term from 21-PWR Yucca Mountain Waste Package)



Cermets Maximize Cask Capacity: Potential Economic/Operating Advantage

- Better shielding materials result in higher capacity casks for a given weight limit
- Cermets may be the best shielding material
- Other candidates eliminated because of repository requirements
  - Unacceptable neutron absorbers
    - Cement (adverse pH and geochemistry)
    - Organics (corrosion of WP)
  - Unacceptable gamma shields
    - Lead (RCRA metals not accepted)
    - Tungsten (high costs)

Cermet Benefit: Cermet Casks May Enhance Protection Against Assault (FY 2002 Activity)



- **Hard/soft layers used in bank vaults and and tank armor**
- **Non-uranium cermets are used in tank armor**
- **Cermet properties harden casks against assault**
  - **DUO_2 hard layer**
  - **Steel soft ductile layer**
- **Design trade-offs not well understood**

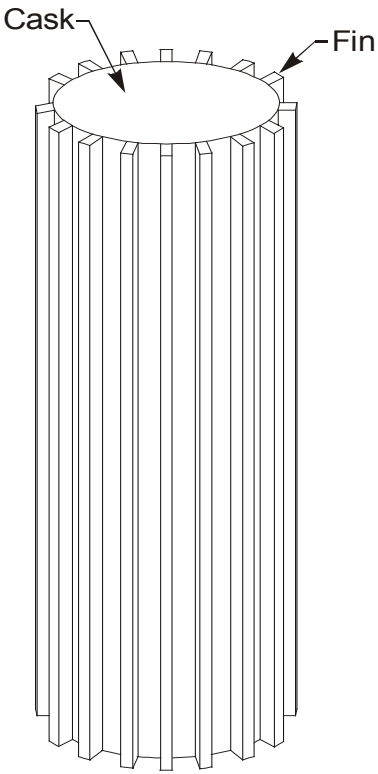
Cermets Are More Attractive If Casks Can Accept High Heat Loads

- If cask capacity limited by weight or size
  - Larger-capacity cask lowers costs
  - Cermets maximize shielding performance with minimum weight and size, thus maximize cask capacity
- If cask capacity limited by decay heat
  - Options to avoid limit: store SNF before cask loading until decreased decay heat, use smaller casks, or cask is partly loaded with SNF
  - Heat removal limited by (1) heat transfer from SNF through basket to cask body and (2) cask body to air [the temperature drop across the cermet cask is small]
  - If remove heat-load constraint, weight limits cask: conditions that favor cermet casks

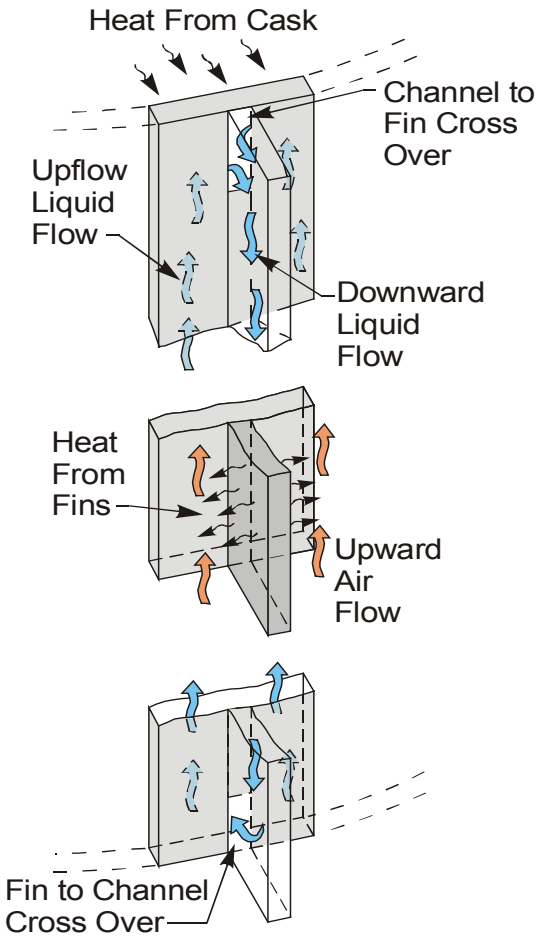
Removable Liquid-Fin Cooling Jackets Are Being Examined (FY 2002) To Enhance Cask Cooling

(Remove After Decay-Heat Decreases and Before Repository Overpack)

Cask



Liquid-Filled Fin

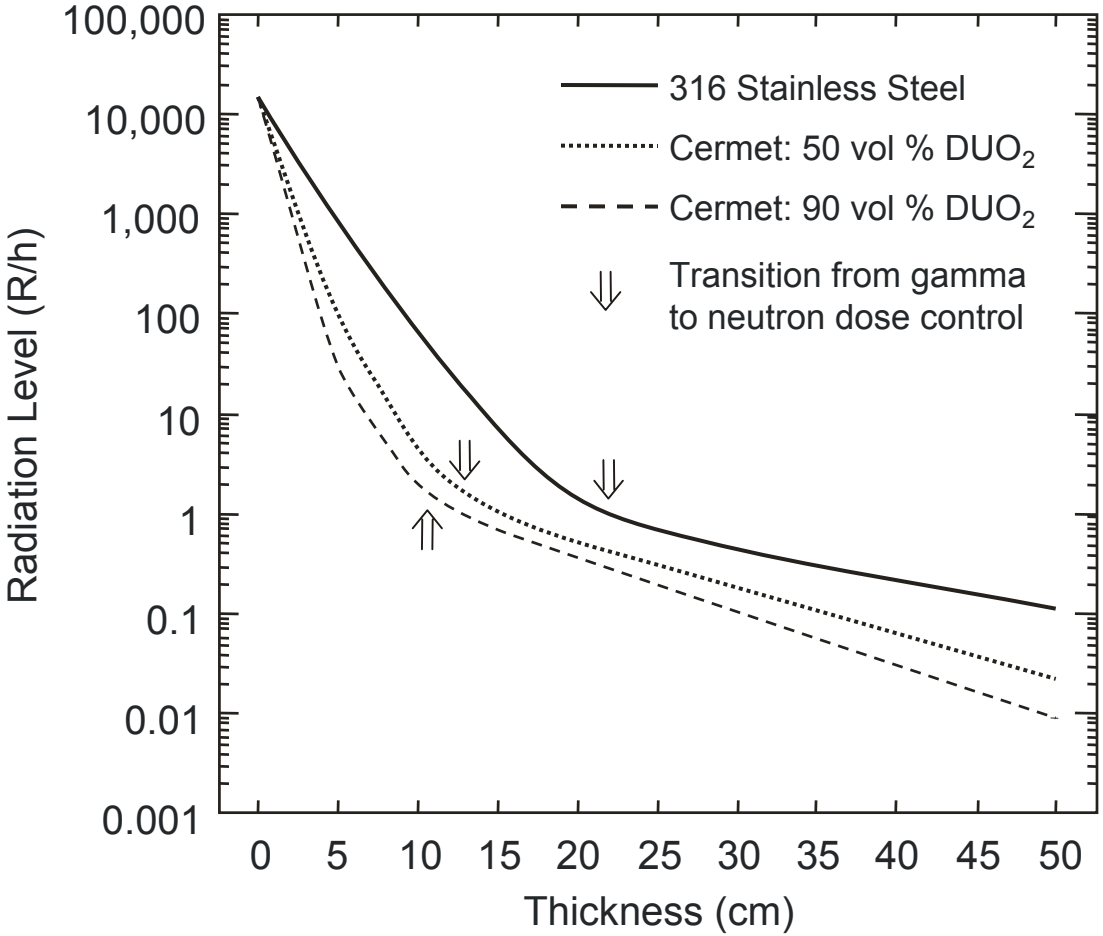


Graphite Is Being Examined To Improve Basket Heat Removal and Neutron Shielding

- Acceptable for repository operations
- Baskets contain thermal shunts to transport heat from SNF to cask body
  - Aluminum is currently used
  - Directional graphite has better performance
- Graphite provides neutron moderation for improved neutron shielding
  - Maximum SNF burnup is increasing
  - Neutron dose, that increases with burnup, may ultimately control shielding requirements

Cermets Are Better Gamma Shields Than Neutron Shields: Added Carbon (Neutron Moderator) Improves System Performance

(Source Term from 21-PWR Yucca Mountain Waste Package)



Economics

Economics of DU Use Depend on System and Application Costs

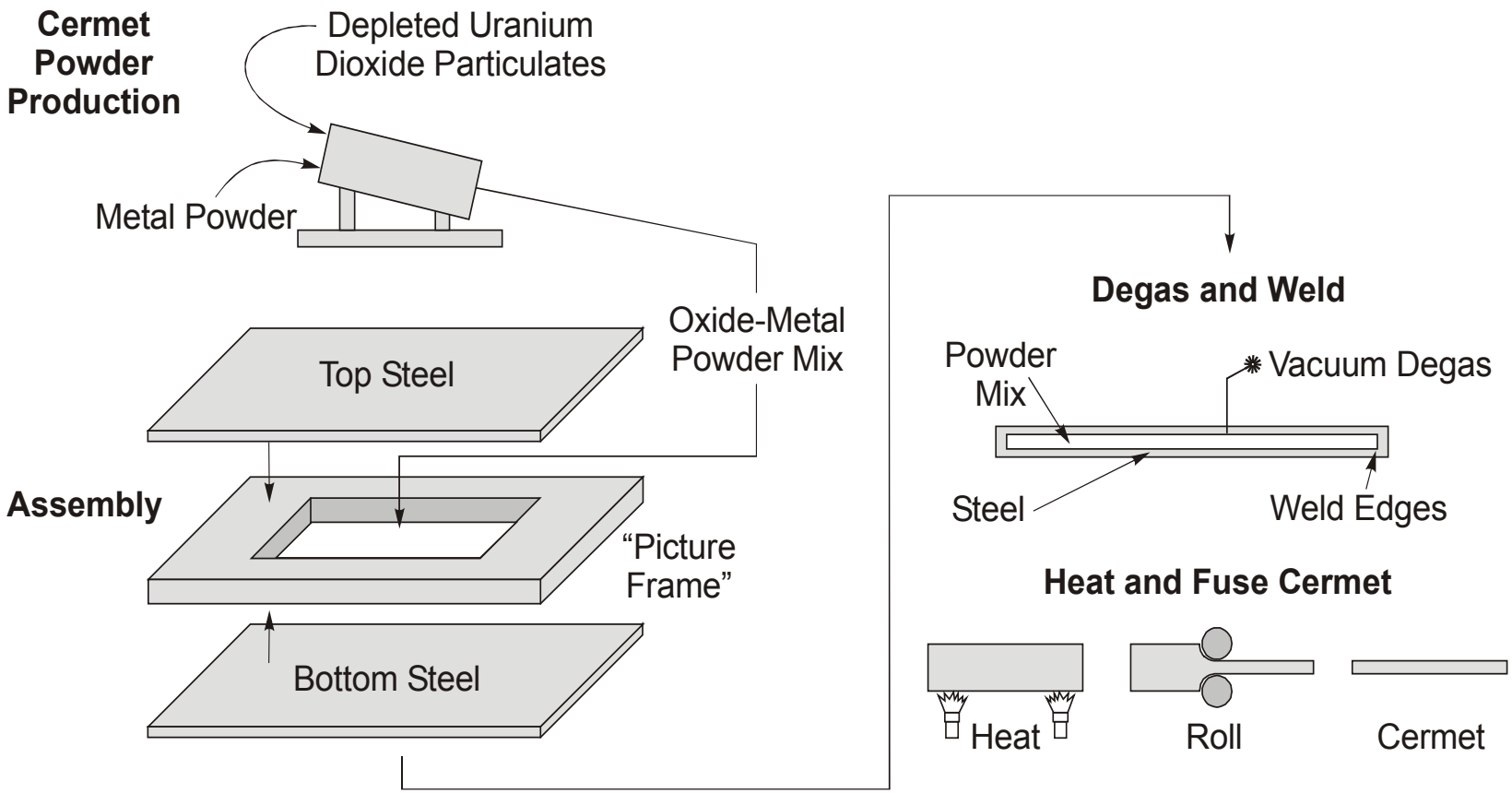
- Future SNF storage and transport requirements (dry storage for all SNF?)
- Need to avoid repository front-end costs
- Potential to replace one or more engineered barriers (titanium drip shield, etc.) with DU: an alternative barrier
- DU disposal costs
- Cost of DU applications (cermet and fill)

Cermet Economics

- Non-nuclear cermets manufactured inexpensively on a large scale
- UO_2 cermet experience with fuel production (low volume, high costs)
- Industrial partnerships (ORNL/other) to explore manufacturing costs

"Picture-Frame" Method for Cermet Production

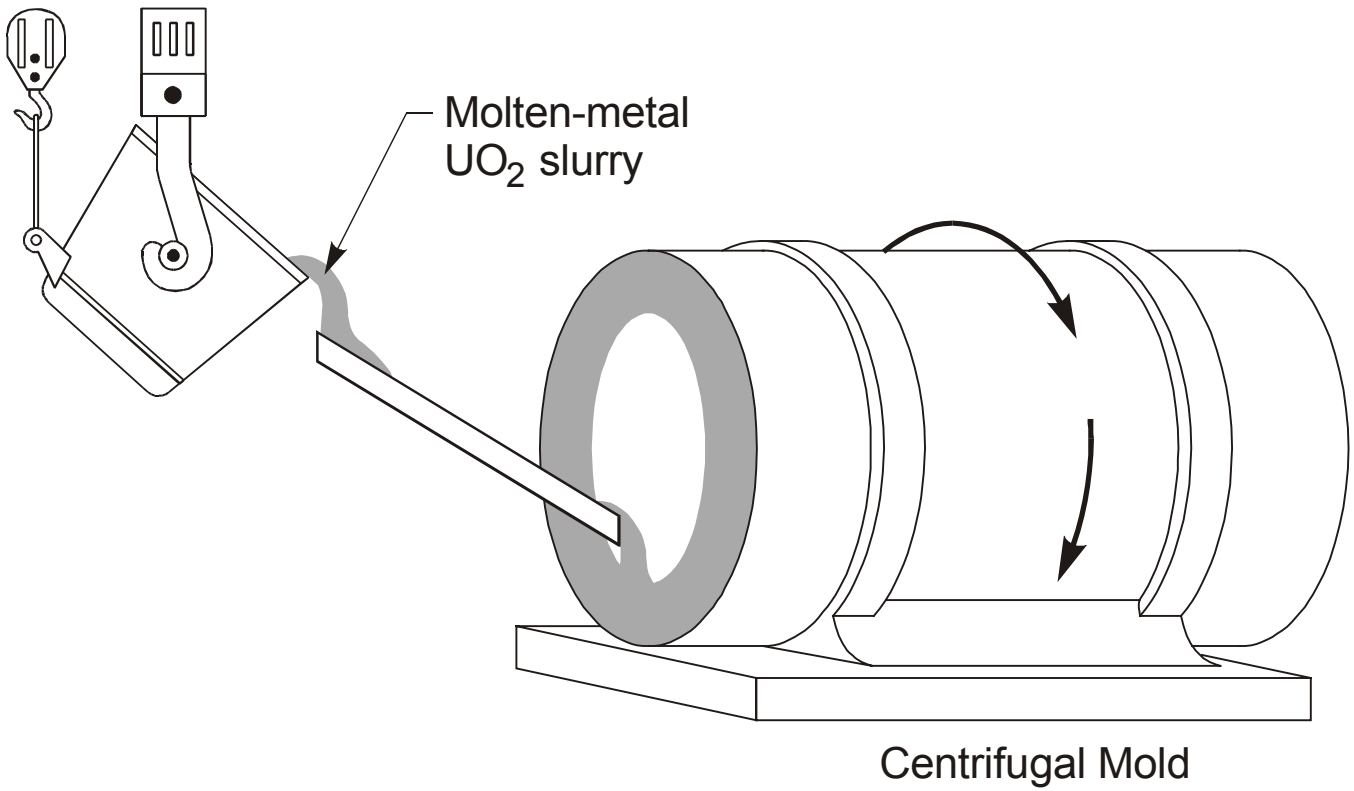
(Used for Some Nuclear Reactor Fuels and Some Nonnuclear Applications)



Centrifugal Casting May Allow Low-Cost Fabrication of Cask Body

- Some nonnuclear cermets manufactured by molten-metal ceramic-particulate slurry casting with solid ceramic particles
- Centrifugal casting is used for sewer pipes and other low-cost products
- R&D is required to develop method for DUO_2-steel cermets (need to ensure wetting of steel and DUO_2 surface)

Centrifugal Casting of Cask Body
(Potentially Very-Low-Cost Option)



There Are Several Markets With Different Economic Drivers

- United States
  - YMP/Utilities (integrated, unified system)
  - Utilities/Enrichment services supplier
    - Long-term responsibility for future DU uncertain
    - DOE/NRC may have different disposal requirements
- Russia/Europe
  - Russian proposal to store foreign SNF
  - DU excess in Europe (repository disposal required in Germany and France)

Past and Future Plans

FY 2000 Accomplishments

- Interface with potential users concerning fill
  - Peer-reviewed journal article (*Nuclear Technology*)
    - Concept description
    - Benefits
    - Uncertainties
  - Spectrum paper in the YMP waste package session
  - YMP considering fills for criticality applications (DOE SNF)
- Identification and preliminary analysis of key technical issues with fill (go/no-go issues)
- Identification of cermet concept
  - Introduced concept
  - Held discussions with multiple programs

FY 2001 Accomplishments

- Fill applications (address go/no-go issues)
  - Heat transfer analysis showed that fills met thermal requirements
  - Analysis of bed behavior indicated acceptable performance
- Cermet applications
  - Defined the properties and radiation shielding characteristics
  - Potential new applications
    - YMP interest in cold repositories (open for 100-300 years)
    - Russian storage of foreign SNF
- Repository interface
  - Working with YMP on assumptions for cermet studies
  - Initiating joint activities with Russian scientists

FY 2002 Activities

- Completed
  - Multipurpose cask system configuration
  - Chemically reducing behavior in WP
- Multipurpose cask option feasibility issues
  - Armor potential
  - Enhanced cooling
  - Graphite for cooling and shielding
- Industrial partnerships (Cermet cost)
- Miscellaneous DOE SNF disposal
  - Thermodynamic evaluation

Scientific Issues

- **Quantification of DU repository benefits**
  - **Sorption measurements of radionuclides (Np, Tc, etc.) on uranium degradation products in repositories**
  - **Modeling of WP evolution**
- **Slurry casting of cermets (very low cost to manufacture)**
  - **Casting slurry of molten metal and DUO_2 solid particulates**
  - **Finding appropriate steel/DUO_2 wetting agents for high-performance very-low-cost cermet)**
- **Multipurpose cask**
  - Properties of DUO_2 cermets for armor

Conclusions

- Identified DU use options and characteristics
- Most (but not all) feasibility issues answered
- Significant development work is needed to understand tradeoffs (cost, performance)
- Trends are toward an integrated SNF system
  - NRC decisions may determine viability
  - Near-term YM emphasis is licensing (alternatives considered for Phase II)
- Problem of scope (small program with complete once-through back-end system)

Cermet, Fill, and Related References

(Current DU Program, Earlier Investigations, and ^{233}U Disposition Program)

- C. W. Forsberg, "Depleted Uranium Dioxide-Steel Cermets for Spent Nuclear Fuel Multipurpose Casks," *American Nuclear Society Fifth Topical Meeting on DOE Spent Nuclear Fuel and Fissile Materials Management, Charleston, South Carolina, September 17–20, 2002* (in preparation).
  - Description of multipurpose cask concept, functions of the over packs, and example design.
- C. W. Forsberg and L. R. Dole, "Converting Miscellaneous SNF to a 'Single' Waste Form by Packaging in Depleted Uranium Oxides," *American Nuclear Society Fifth Topical Meeting on DOE Spent Nuclear Fuel and Fissile Materials Management, Charleston, South Carolina, September 17–20, 2002* (in preparation).
  - First description of using DU to drive DOE SNF waste package geochemistry to look like commercial SNF.
- C. W. Forsberg, "Rethinking Multipurpose Spent Nuclear Fuel Casks and Canisters: A Depleted Uranium Dioxide-Steel Cermet Multipurpose Cask, *Spent Fuel Management Seminar XIX*, Institute of Nuclear Materials Management, Washington, D.C., January 9–11, 2001.
  - Basis for rethinking multipurpose casks. The concept of a multipurpose cask is old. Terrorist events, restructuring of the utilities, and the potential licensing of YM have created a new set of conditions where the concept should be reconsidered.
- C. W. Forsberg and L. R. Dole, "Depleted Uranium Dioxide Waste Package for Spent Nuclear Fuel," *Scientific Basis for Nuclear Waste Management XXV*, Editors: B. P. McGrail and G. A. Cragnolino, Materials Research Society, Warrendale, Pennsylvania.
  - Estimation of the time a WP may remain under chemically reducing conditions if the package uses a DUO_2 cermet.

Cermet, Fill, and Related References

(Current DU Program, Earlier Investigations, and ^{233}U Disposition Program)

- C. W. Forsberg, "Repository Criticality Control With Depleted-Uranium-Dioxide Cermet Waste Packages," *Topical Meeting on Practical Implementation of Nuclear Criticality Safety*, American Nuclear Society, Reno, Nevada, November 11–15, 2001.
  - Technical basis for long-term repository criticality control using a DUO_2 cermet.
- C. W. Forsberg, *Depleted Uranium Applications in Geological Repositories*, U.S. Department of Energy/Russian Academy of Science Depleted Uranium Workshop, Moscow, Russia, October 22–23, 2001, (accepted).
  - Summarizing DUO_2 cermets and fill concepts for Russian workshop. Terrorist events have delayed workshop.
- C. W. Forsberg, L. B. Shappert, P. Byrne, and B. Broadhead, "Cermet Transport, Storage, and Disposal Packages Using Depleted Uranium Dioxide (DUO_2) and Steel," *13th International Symposium on the Packaging and Transportation of Radioactive Materials, U.S. Department of Energy, Chicago, Illinois, September 3–7, 2001*.
  - Description of DUO_2 cermet cask for aged SNF; characteristics (shielding capabilities); and physical properties (strength, thermal conductivity, density, etc.)
- C. W. Forsberg, "Depleted-Uranium Dioxide As SNF Waste Package Particulate Fill: Engineering Properties," *2001 International High-Level Radioactive Waste Management Conference, Las Vegas, Nevada, April 29–May 3, 2001*, American Nuclear Society, La Grange Park, Illinois.
  - Description of particulate fill properties with thermal analysis of SNF WP with DUO_2 fill.

Cermet, Fill, and Related References

(Current DU Program, Earlier Investigations, and ^{233}U Disposition Program)

- C. W. Forsberg, "Depleted Uranium Dioxide As A Spent-Nuclear-Fuel Waste-Package Particulate Fill: Fill Behavior," *Waste Management 2001,* Tucson, Arizona, February 25–March 1, 2001.
  - Describes the evolution of DUO_2 fill under oxidizing groundwater conditions to silicate form. Includes evolution under wet and dry oxidizing conditions.
- C. W. Forsberg, "Depleted Uranium Dioxide as SNF Waste Package Fill: A Disposal Option," *Spectrum 2000: International Conference on Nuclear and Hazardous Waste Management, Chattanooga, Tennessee, September 24–28, 2000*, American Nuclear Society.
  - Describes fill concept, the quantities of DUO_2 fill that can be placed inside a WP under different sets of assumptions, the resultant package weights, and package average enrichments.
- C. W. Forsberg, "Effect of Depleted-Uranium-Dioxide Particulate Fill on Spent-Nuclear-Fuel Waste Packages," *Nuclear Technology*, 131: pp. 337–353 (September 2000).
  - Detailed journal article on DUO_2 fill concept.
- K. R. Elam, C. W. Forsberg, C. M. Hopper, and R. Q. Wright, *Isotopic Dilution Requirements for ^{233}U Criticality Safety in Processing and Disposal Facilities*, ORNL/TM-13524, Oak Ridge National Laboratory, Oak Ridge, Tennessee (November 1997).
  - Defines how much ^{238}U is required to make ^{233}U nuclear criticality not credible under various storage and geological conditions.

Cermet, Fill, and Related References

(Current DU Program, Earlier Investigations, and ^{233}U Disposition Program)

- C. W. Forsberg, *Description of the Canadian Particulate-Fill Waste-Package (WP) System for Spent-Nuclear Fuel (SNF) and Its Applicability to Light-Water Reactor (LWR) WPs with Depleted Uranium-Dioxide Fill*, ORNL/TM-13502, Oak Ridge National Laboratory, Oak Ridge, Tennessee, October 20, 1997.
  - Summarizes results of Canadian program on adding fill to WPs.
- C. W. Forsberg, "Long-Term Criticality Control in Radioactive Waste Disposal Facilities Using Depleted Uranium," pp. 99–106 in *Proc. Topical Meeting: Criticality Safety Challenges in the Next Decade, Chelan, Washington, September 7–11, 1997*, American Nuclear Society, La Grange Park, Illinois, September 1997.
  - Describes geochemical scenarios for recriticality in a repository environment and methods to prevent such criticality events.
- C. W. Forsberg, "Long-Term Criticality Control in Radioactive Waste Disposal Facilities," *Nuclear Safety*, 38(1):60–69 (January–March 1997).
  - General criticality control strategies for different types of waste management facilities.
- C. W. Forsberg, "Depleted Uranium Oxides and Silicates as Spent Nuclear Fuel Waste Package Fill Materials," pp. 615–622 in *Symp. Proc. Scientific Basis for Nuclear Waste Management XX, December 2–6, 1996, Boston, Massachusetts*, Vol. 465, Materials Research Society, 1997.
  - Analysis of the geochemistry of DU oxide/silicate fills and impacts on repository performance

Cermet, Fill, and Related References

(Current DU Program, Earlier Investigations, and ^{233}U Disposition Program)

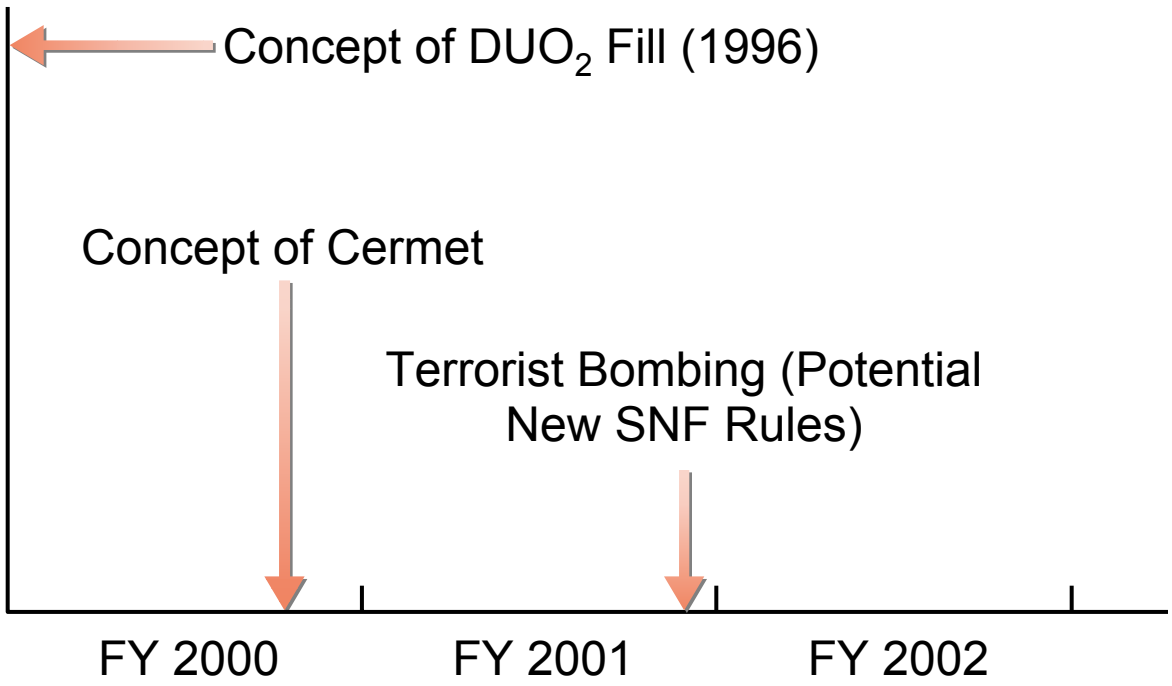
- C. W. Forsberg, R. B. Pope, R. C. Ashline, M. D. DeHart, K. W. Childs, and J. S. Tang, *DUSCOBS—A Depleted-Uranium Silicate Backfill for Transport, Storage, and Disposal of Spent Nuclear Fuel*, ORNL/TM-13045, Oak Ridge National Laboratory, Oak Ridge, Tennessee (November 1995).
  - Initial analysis of DU silicate fill for SNF WPs.

Patents

- C. W. Forsberg, *Depleted Uranium as a Backfill for Nuclear Fuel Waste Packages*, U.S. Patent 5,832,392 (November 3, 1998).

Backup Information

Applications for Repository Use of DU Have Been Identified and Developed over Time



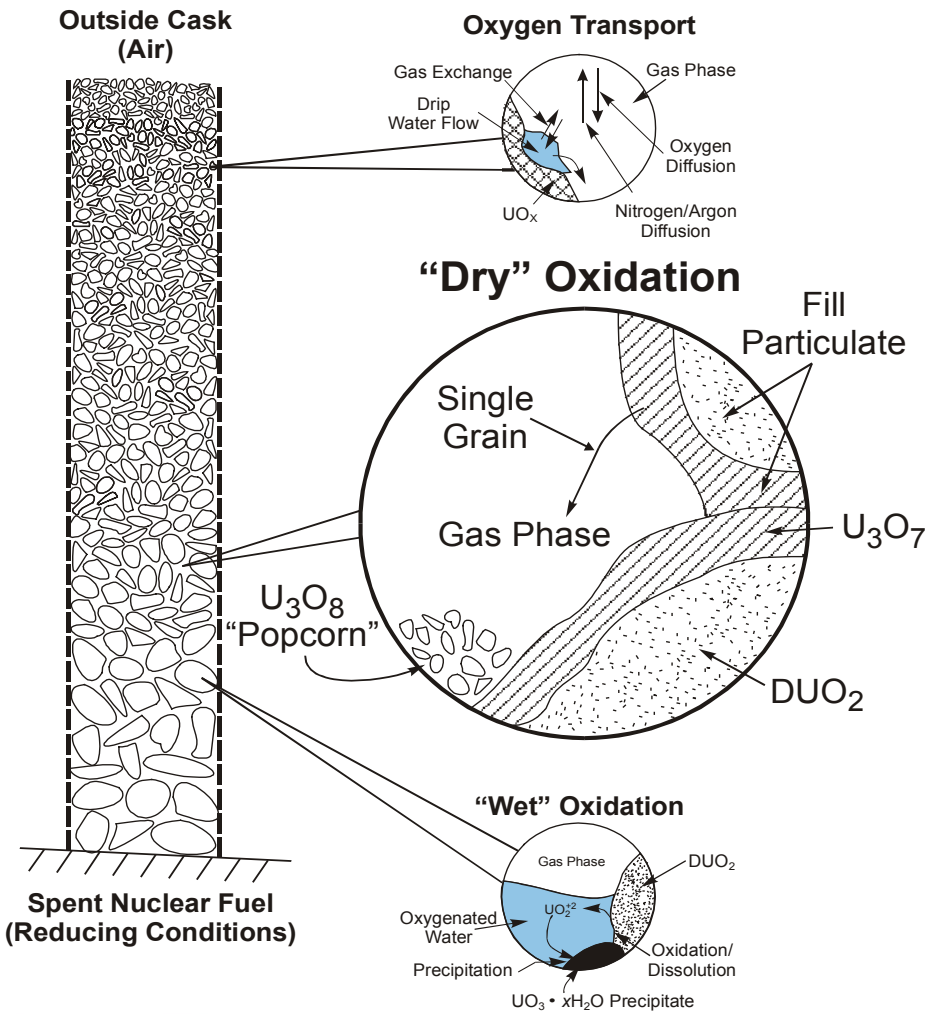
Swedish Programs Are Developing Detailed Kinetic Models of WP Performance Under Reducing Conditions

(Liu and Neretnieks, Nuclear Tech., March-April 2002)

- YMP emphasis on oxidizing groundwater
  - WP becomes oxidizing upon failure
  - Little work on reducing environments
- Swedish models address UO_2 and iron
  - LWR SNF
  - Steel package with copper exterior liner
- Swedish work on reducing WP conditions applicable to Stage 2 disposal

Dry DUO_2 Oxidation Slows SNF Degradation

(Oxidation Increases the Oxide Volume, Breaks Fill Particulates into Smaller Grain-Size Particles, Slows Fluid Flow, and Thus Slows Further Oxidation)



Strategy for DOE SNF

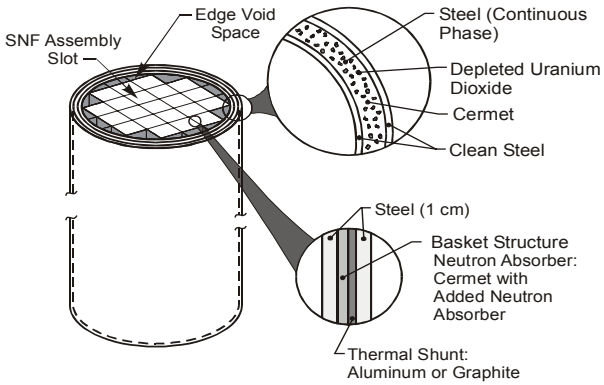
- DOE SNF Characteristics
  - Highly variable
  - Small quantities
- Strategy
  - Maximize DUO_2 in WP
  - Drive geochemistry to uranium system
  - "Looks like" commercial SNF
- Strategy currently being investigated (FY2002)

Incentives: Utility Industry Consolidation Encourages Introduction of Multipurpose Casks

- Consolidated siting more likely (transport/storage casks)
- Modified cask design
  - Fewer cask types (more casks of each type)
  - Acceptance of higher manufacturing setup costs if lower per-cask cost
- Altered repository interface (limited number of organizations)
  - Negotiate SNF management interface
  - Increased possibility for multipurpose cask

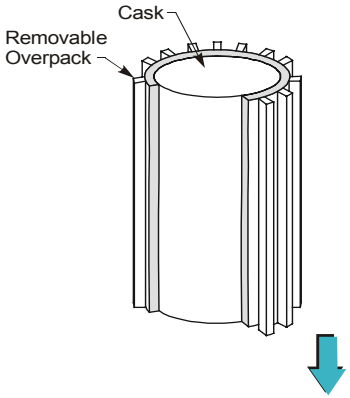
Multipurpose Cask for Storage, Transport, and Disposal

Multipurpose Cask



- Radiation Shielding
  - Gamma: High-Density Cermet
  - Neutron Moderation/Absorption
    - Oxygen in Cermet
    - Carbon in Cask
- Assault Protection: Multilayer Cermet
- Safeguards and Theft
  - Large Mass
  - Vault Construction: Multilayer Cermet
- Decay Heat Removal
  - Carbon Shunt (also Neutron Moderator)
  - Aluminum

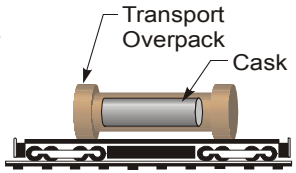
Multipurpose Cask System



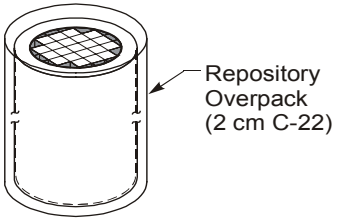
Storage at Reactor With Overpack for Short-Cooled SNF

Removable Overpack
- Augmented Cooling
  - Dry Fin
  - Liquid Fin
- Augmented Shielding

Transport



Disposal at Repository With Overpack



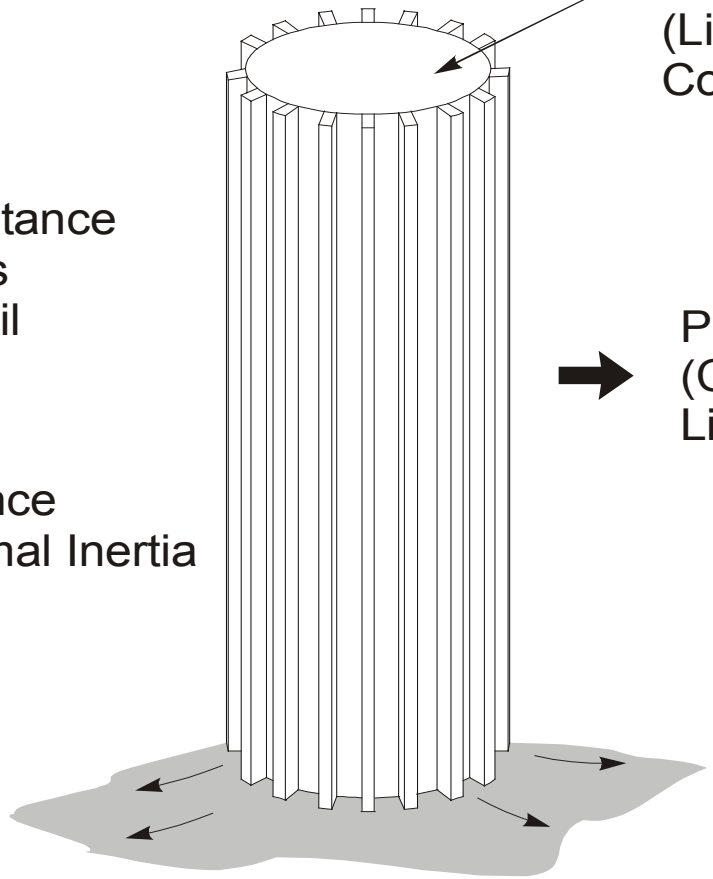
German Rail Gun For Testing Casks: 1 Ton Projectile At 300 m/s

In Severe Environments, Casks Have Potential Advantages over Pools and Other SNF Storage Methods

(Casks Used In Germany: Aircraft Collision Requirement)

Limited Inventory (Limited Consequences)

Impact Resistance
- Thick Walls
- Cask Recoil



Passive Cooling (Consequence of Limited Inventory)

Fire Resistance
- High Thermal Inertia
- Drain Fuel