

# **Depleted Uranium Dioxide–Steel Cermets For Spent–Nuclear–Fuel Multipurpose Casks**

**Dr. Charles W. Forsberg  
Dr. M. Jonathan Haire**

**Oak Ridge National Laboratory\*  
P.O. Box 2008; Oak Ridge, TN 37831-6179  
Tel: (865) 574-6783; E-mail: forsbergcw@ornl.gov**

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# Overview

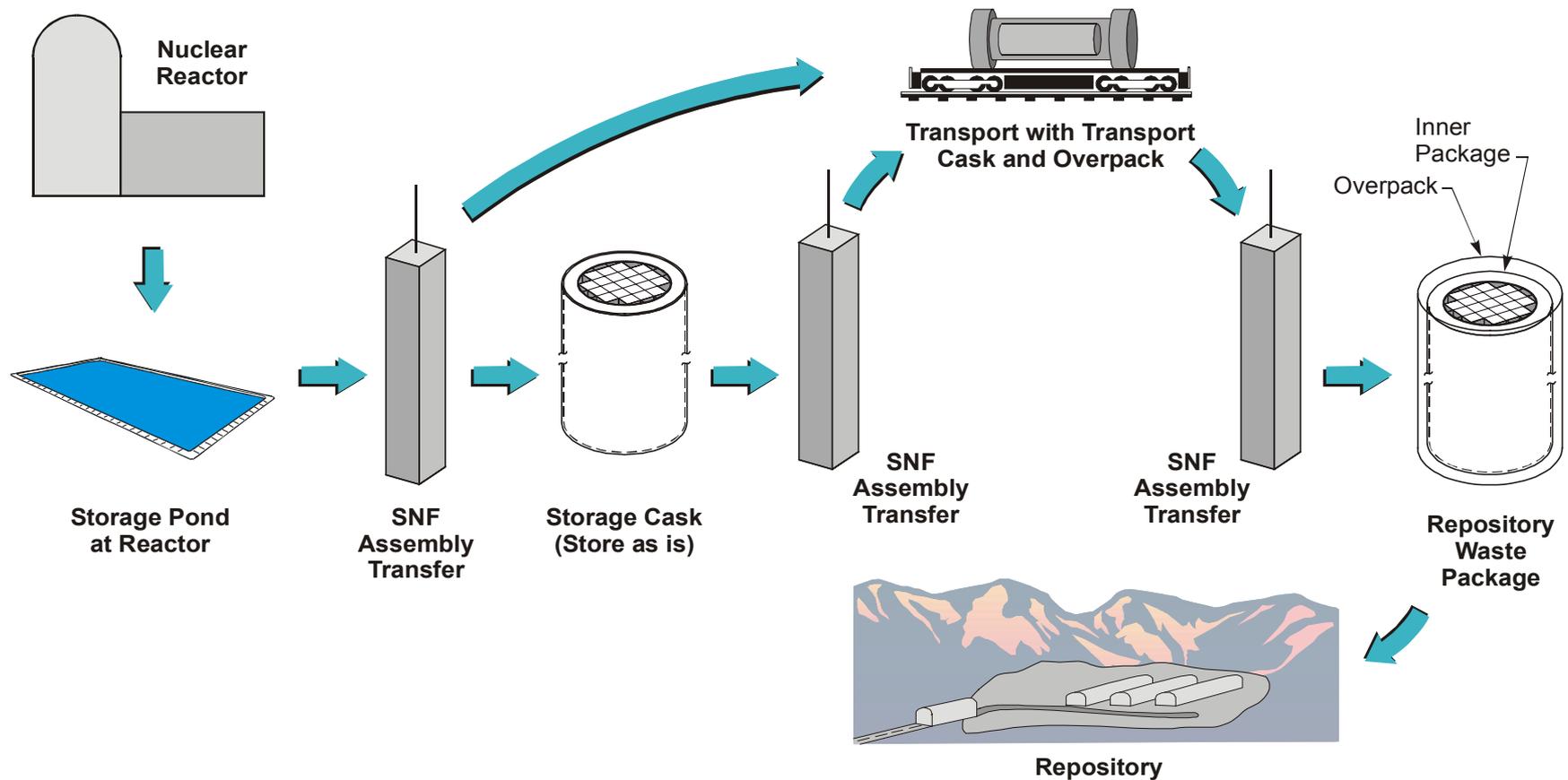
- **The nuclear fuel cycle was designed for recycle of spent nuclear fuel (SNF) and has evolved into a once-through fuel cycle**
- **A fuel cycle designed as a once-through system would be different from the current one**
- **Proliferation, safeguards, security (terrorism), and economics suggest that the current once-through fuel cycle needs to be reevaluated**
- **A new approach to SNF cask operations and design is proposed**

# Outline

- **Current Once-Through Spent Nuclear Fuel (SNF) Management Strategy**
- **An Advance Once-Through SNF System**
- **Depleted Uranium Dioxide–Steel Cermet Multipurpose Casks**
- **Conclusions**

# **Current Once-Through Spent Nuclear Fuel (SNF) Management Strategy**

# Traditional Approaches to SNF Management Imply Multiple Handling of Individual Assemblies With Associated Costs and Risks



# **An Advance Once-Through Fuel Cycle**

**An Advanced Option For Future SNF Not  
Already In Existing Storage Systems**

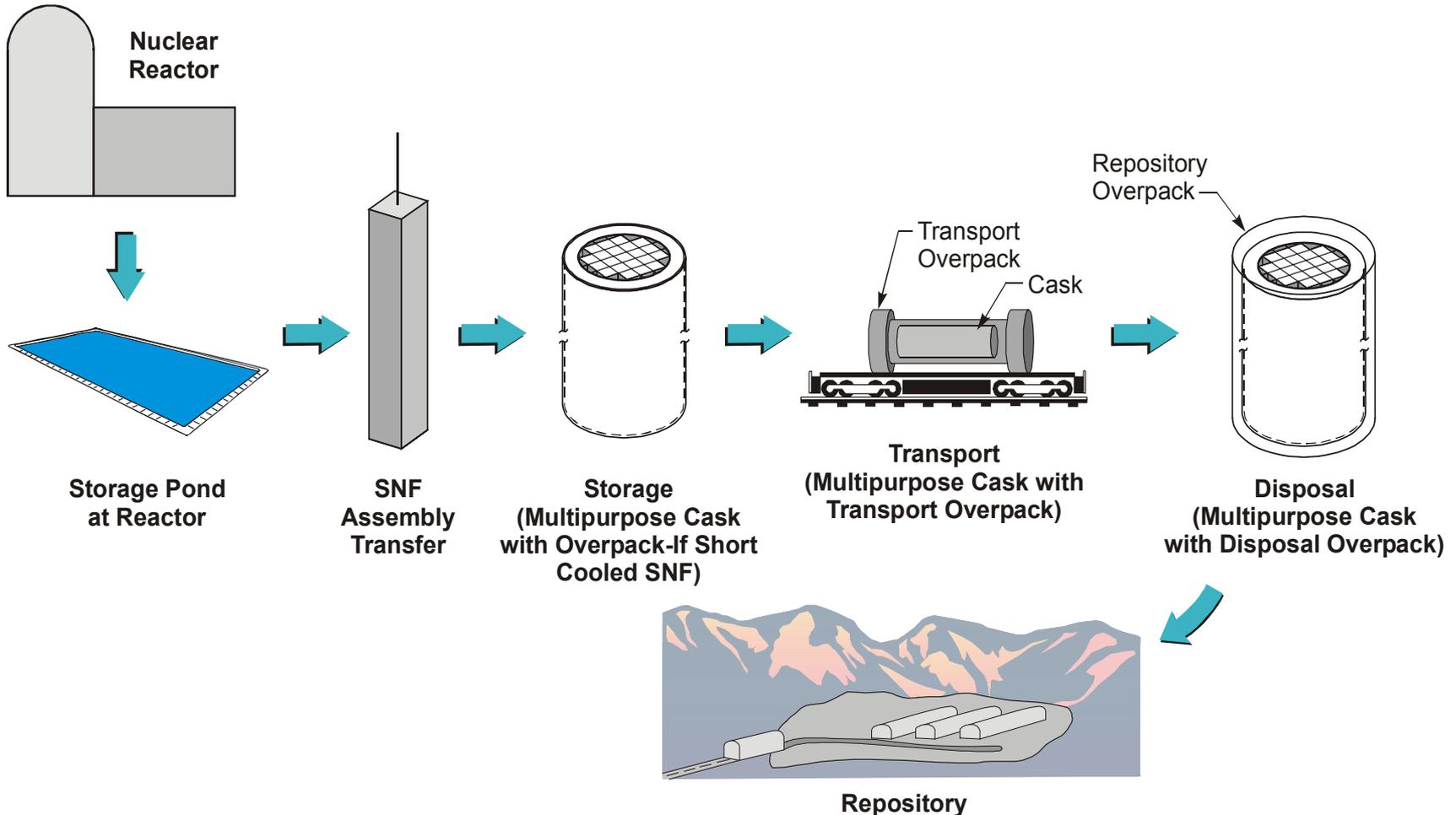
# Current System Used Worldwide Has Avoidable Disadvantages

- **History**
  - Originally designed for recycle of SNF
  - Evolved into a once-through system
  - Significant differences between a system designed specifically for a once-through fuel cycle and the one that has evolved
- **Alternative systems could improve security and safeguards with lower costs. Current system characteristics:**
  - Multiple handling of SNF
  - High dependence on expensive active security and safeguards
- **Increased knowledge of repository requirements (as approach licensing) creates the possibility for a fully integrated system**

# **A New Once-Through SNF System Is Proposed To Accomplish Two Objectives While Reducing Costs**

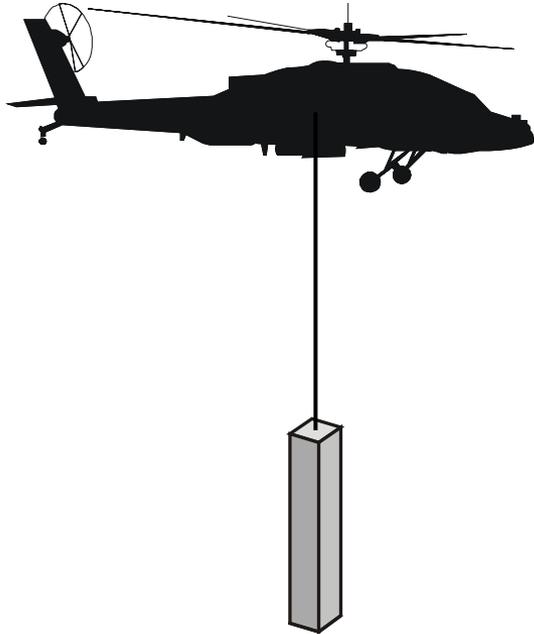
- **Minimize SNF handling**
  - Handling operations are a weak link
  - In the proposed system, SNF assemblies are handled only once between reactor pool and repository (use of multipurpose cask)
  - Added requirements are imposed on the SNF cask
- **Transfer SNF into secure packages (multipurpose Super Casks)**
  - Packages are designed with vault capability
  - Casks are tamper resistant

# Multipurpose Cask Approach Minimizes SNF Handling: SNF Remains in a Movable (100-ton) Vault



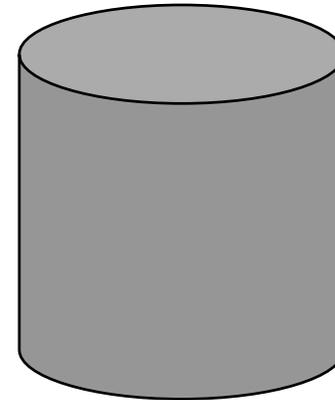
# Multipurpose Casks By Their Characteristics Provide Protection Against Theft Or Diversion

*Fuel Assembly*



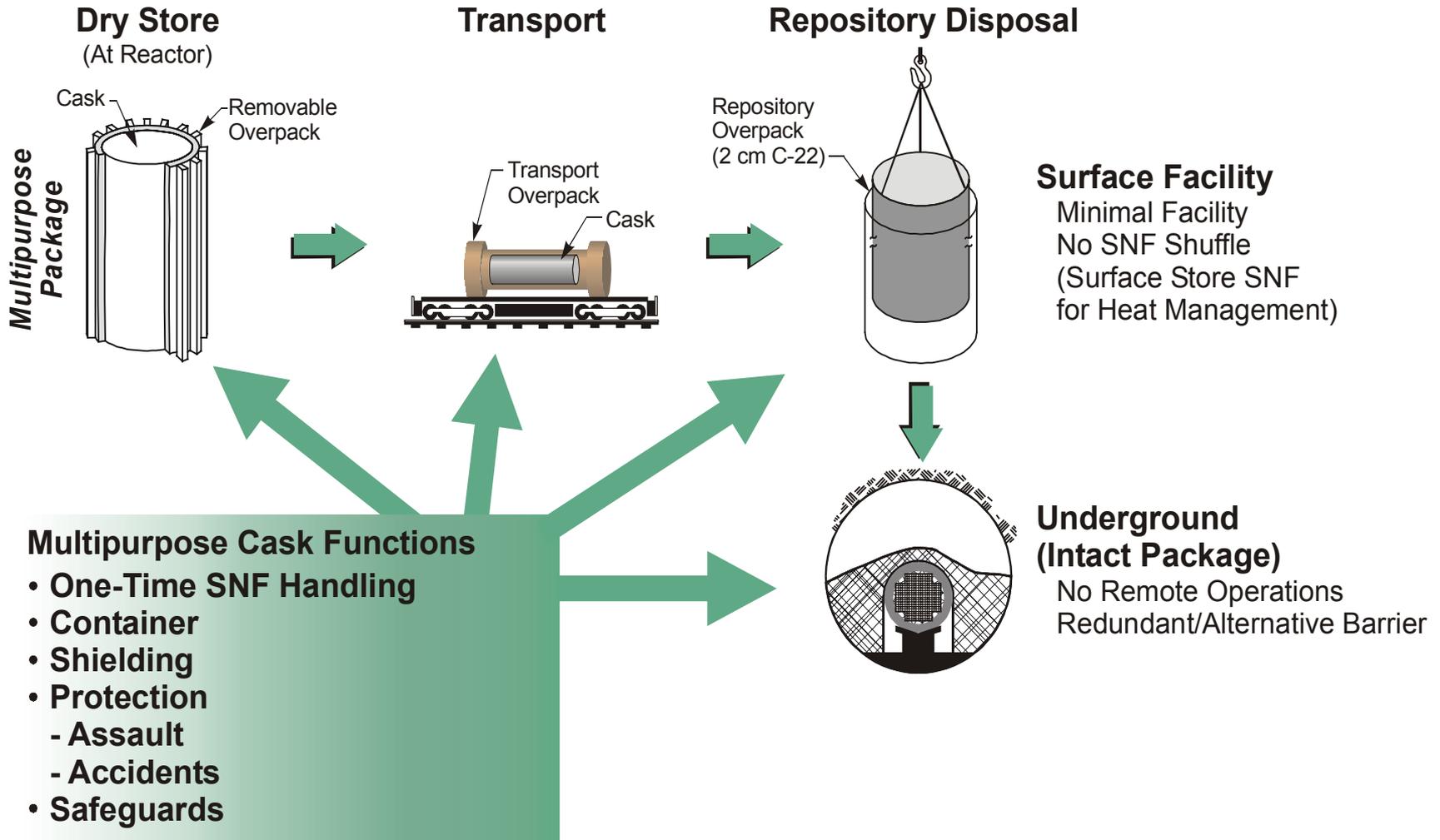
**Low weight (~1/2 ton),  
small size**

*Multipurpose Cask*

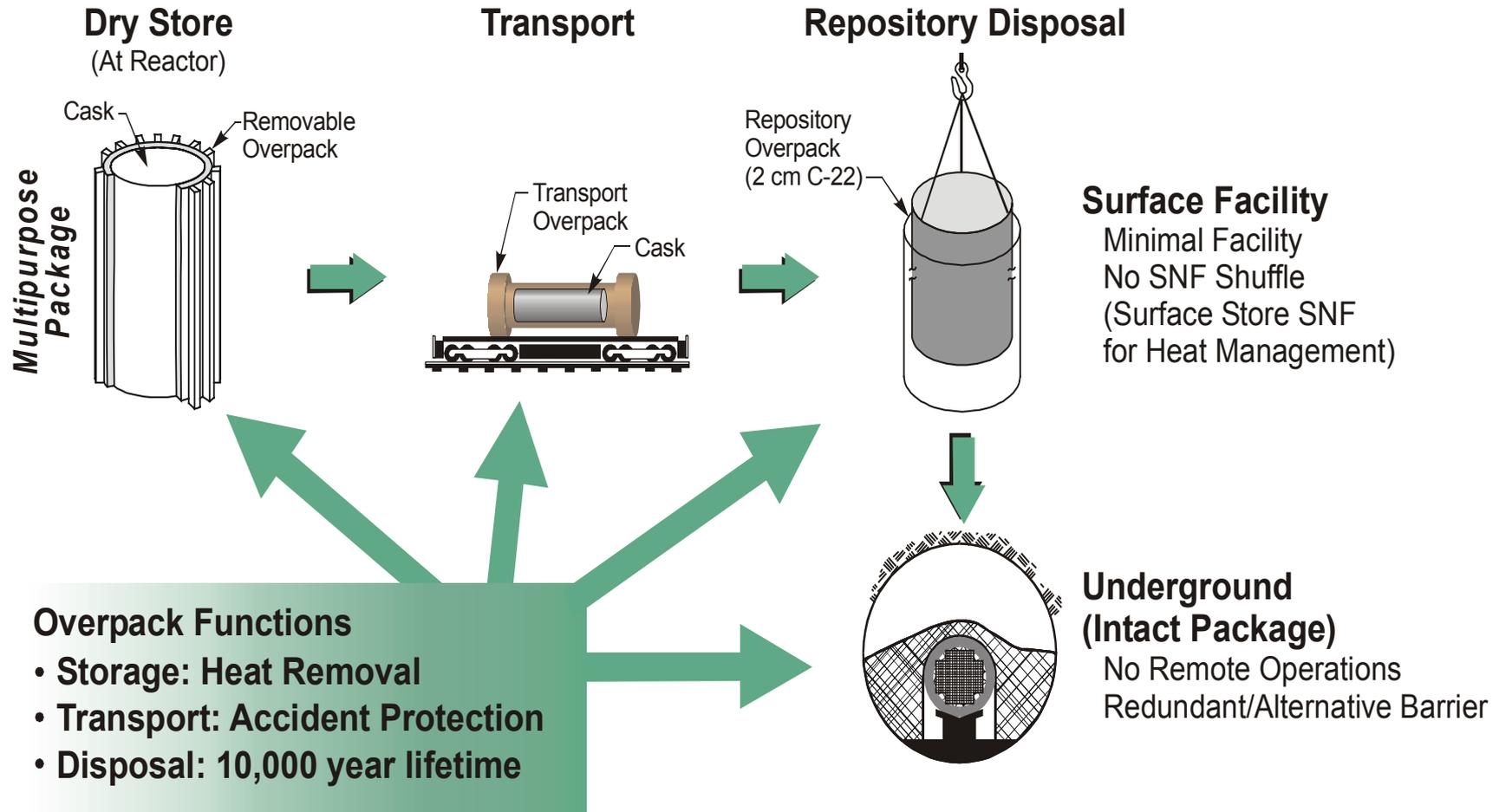


**Large weight (>70 tons),  
large size, detectable from  
from orbit, option of  
transponder**

# Avoidance of Separate Storage, Transport, and Waste Package Systems Can Reduce Total Costs



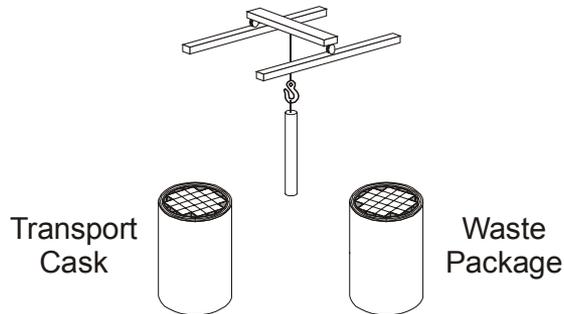
# Overpacks Address Multipurpose Cask Conflicting Storage, Transport, and Disposal Requirements



# Multipurpose Casks May Significantly Reduce Repository Surface Operations, Risks, and Costs

(Meet WP Decay Heat Limits by Storage, Not Sorting of SNF)

## Current System

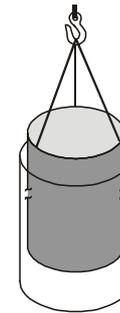


Remote Transfer of SNF

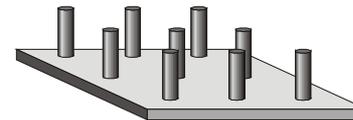


Adjusting Waste Package Heat Load for the Repository

## Multipurpose Cask System



Addition of Overpack



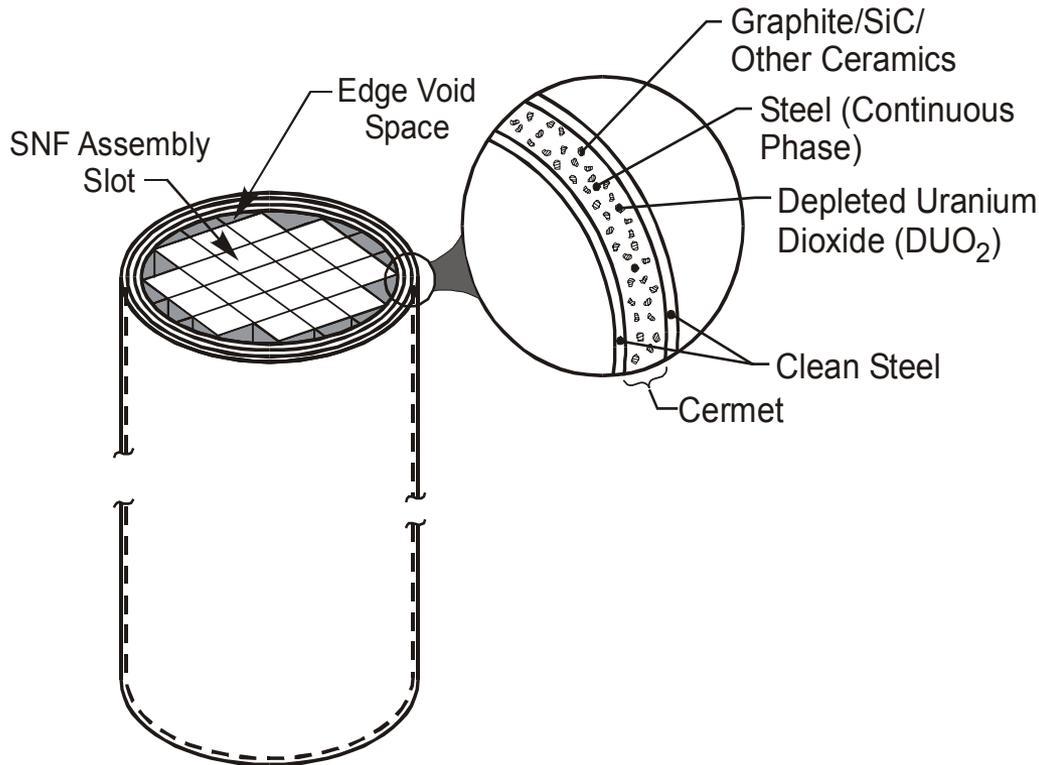
Surface Storage Until Repository Acceptable Heat Load

# **Depleted Uranium Dioxide–Steel Cermet Casks**

**The Viability Of Multipurpose Casks  
Depends Upon Cask Capabilities**

**Depleted Uranium Dioxide (DUO<sub>2</sub>)–Steel  
Cermet Casks May be the Enabling  
Technology For Multipurpose Casks**

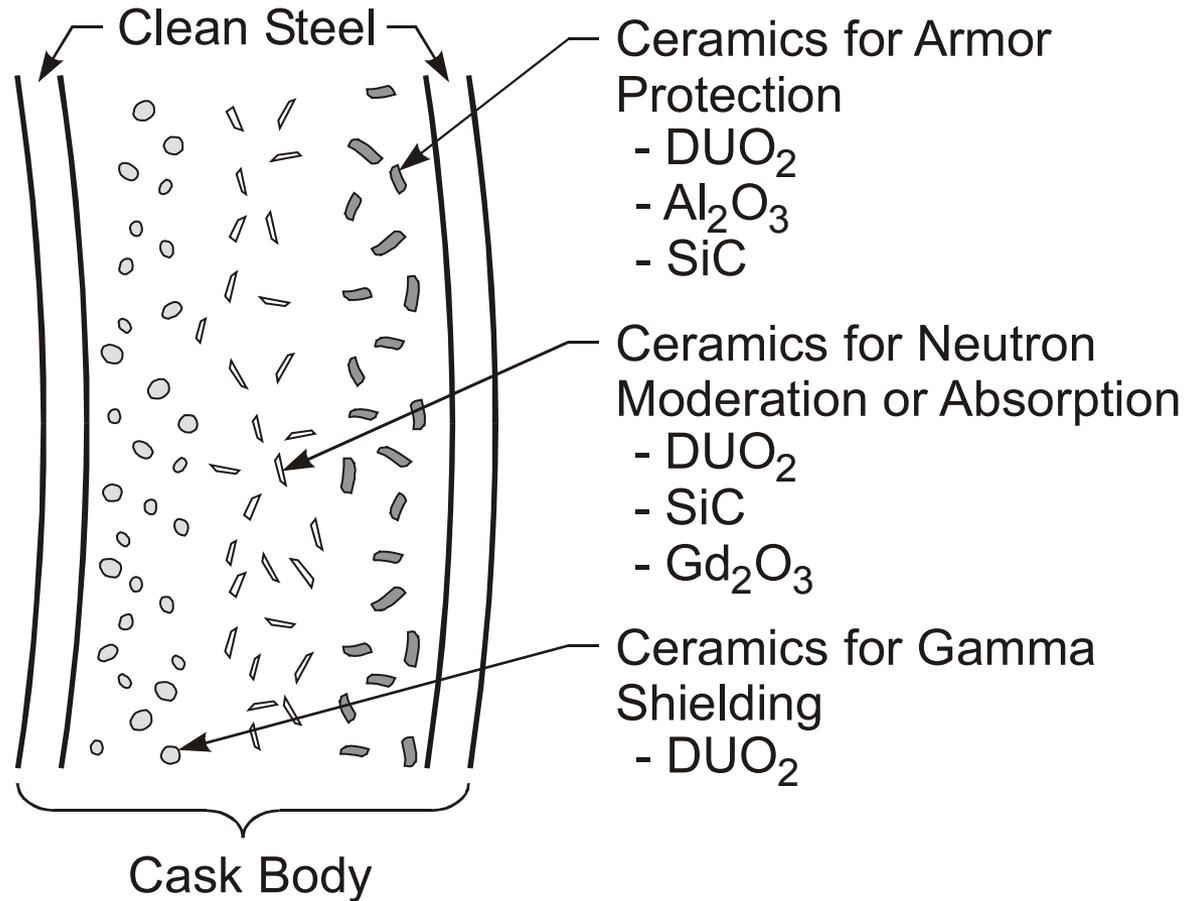
# Cermets (Ceramics in Metal Matrix) Are The Enabling Technology for a High-Performance Multipurpose Cask



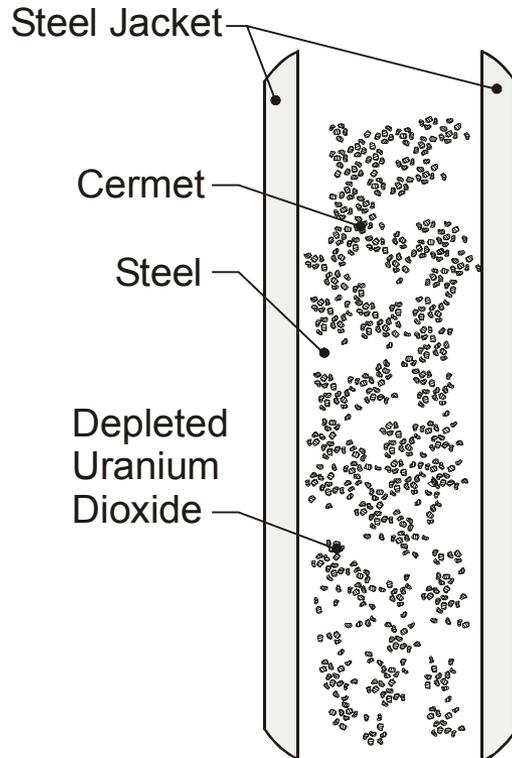
## Functions

- Radiation Shielding
  - Gamma: High-Density DUO<sub>2</sub>/Other
  - Neutron Moderation/Absorption
    - Oxygen in DUO<sub>2</sub>
    - Carbon in SiC and Graphite
- Assault Protection: Multilayer Cermet (Traditional Armor)
  - Ceramic (Al<sub>2</sub>O<sub>3</sub>, DUO<sub>2</sub>, SiC, Other)
  - Metal
- Safeguards and Theft
  - Large Mass
  - Vault Construction: Multilayer Cermet
- Decay Heat Removal
  - High Conductivity Steel Matrix

# The Composition Across the Cermet Can Be Varied To Maximize Performance



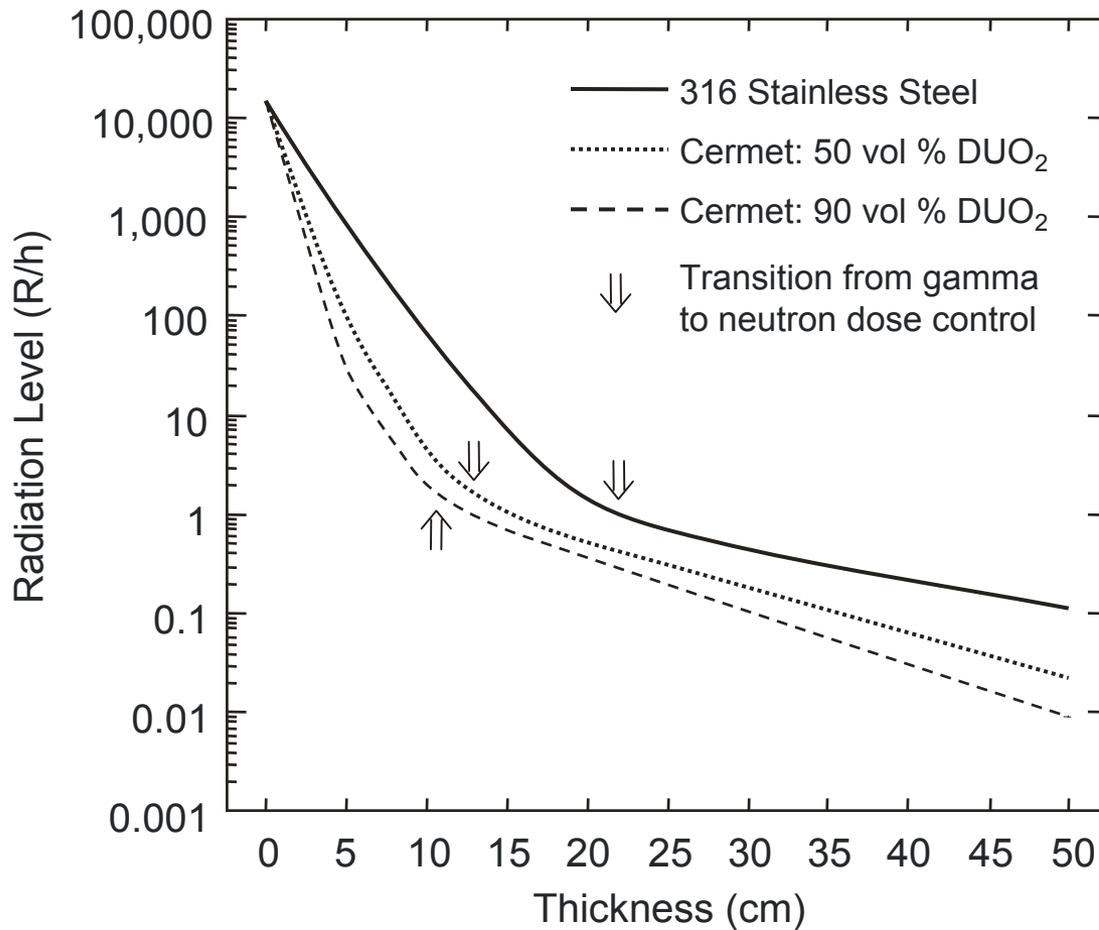
# DUO<sub>2</sub>-Steel Cermets Are Excellent Shielding Materials with Some Unique Capabilities



- Gamma Shielding Better Than Steel
  - Steel: 7.86 g/cm<sup>3</sup>
  - DUO<sub>2</sub>: 10.9 g/cm<sup>3</sup>
- Neutron Shielding
  - High-density oxygen (DUO<sub>2</sub>) moderator
  - Other neutron absorbers can be added
- Good Physical Properties
  - High thermal conductivity
  - No organics (no fire; acceptable to repository)

# DUO<sub>2</sub> Cermets Are Superior Shielding Materials

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

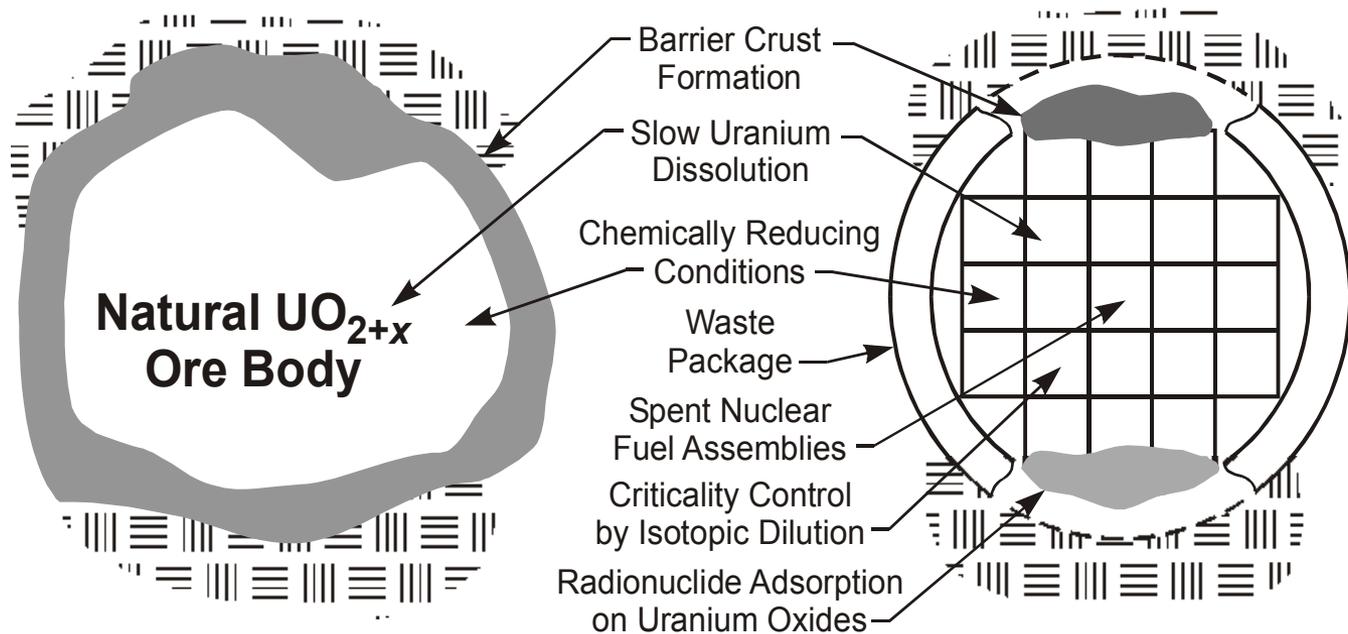


# **Cermets Maximize Cask Capacity: Potential Economic/Operating Advantage**

- **Better shielding materials result in higher-capacity SNF casks for a given weight limit**
- **Cermets are a superior shielding material. Many alternatives are eliminated because they fail to meet repository requirements**
  - **Unacceptable neutron absorbers**
    - **Cement (adverse pH and geochemistry)**
    - **Organics (corrosion of waste package)**
  - **Unacceptable gamma shields**
    - **Lead (RCRA metals not accepted)**
    - **Tungsten (high costs)**

# Some Uranium Ore Deposits Have Remained Intact for Millions of Years: The Same Mechanisms Should Protect SNF in Failed WPs Containing DUO<sub>2</sub>

(DUO<sub>2</sub> Is a Sacrificial Compound that Preserves SNF UO<sub>2</sub>)



# Cermets Casks Can Enhance SNF Physical Protection

- **Armor is used in tanks, bank vaults, and safety systems to protect against:**
  - Attack by man
  - Natural events (tornadoes, etc.)
- **Composite armor is now generally used**
  - A single material is easy to defeat
  - Modern armor has two components
    - Hard material (ceramics)
    - Strong ductile materials (metals)
- **Many types of armor are cermets**

# **There Are Strategic Incentives For Using $\text{DUO}_2$ In The Cermet**

- **Disposes of DU (500,000-ton surplus)**
- **Allows future option of co-recovery of the two materials that are required for a breeder reactor fuel cycle**
  - SNF
  - Depleted uranium
- **Co-disposal of the two long-lived wastes (SNF and depleted uranium)**
  - One disposal site for all long-lived wastes
  - No adverse impact of  $\text{DUO}_2$  on the repository

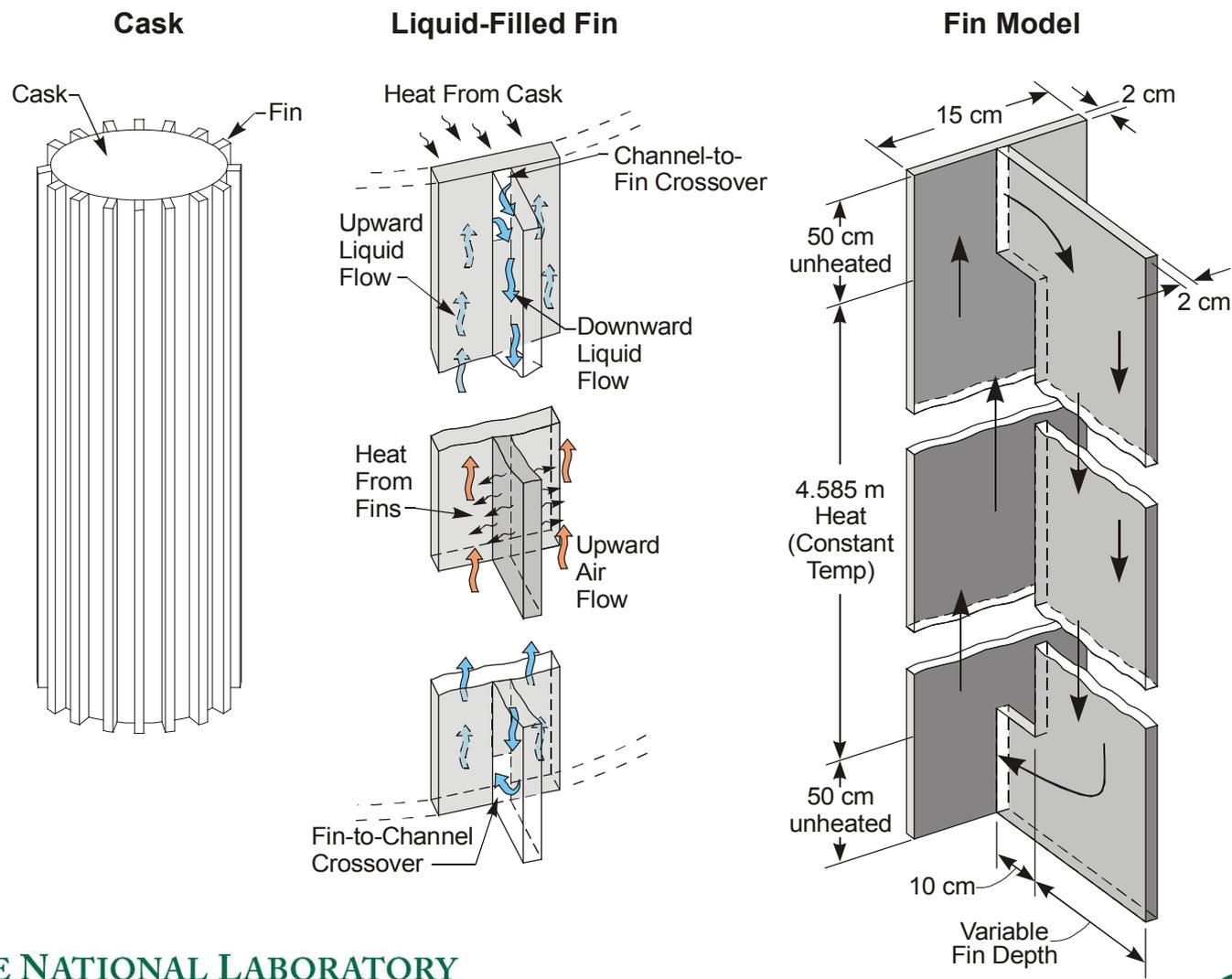
# Conclusions

- **A multipurpose cask system for SNF storage, transport, and disposal has major potential advantages**
- **DUO<sub>2</sub> cermet is an enabling technology that may meet the multiple requirements for a multi-purpose cask system**
- **Potential exists for a significantly-improved integrated once-through fuel cycle**

# Backup Slides

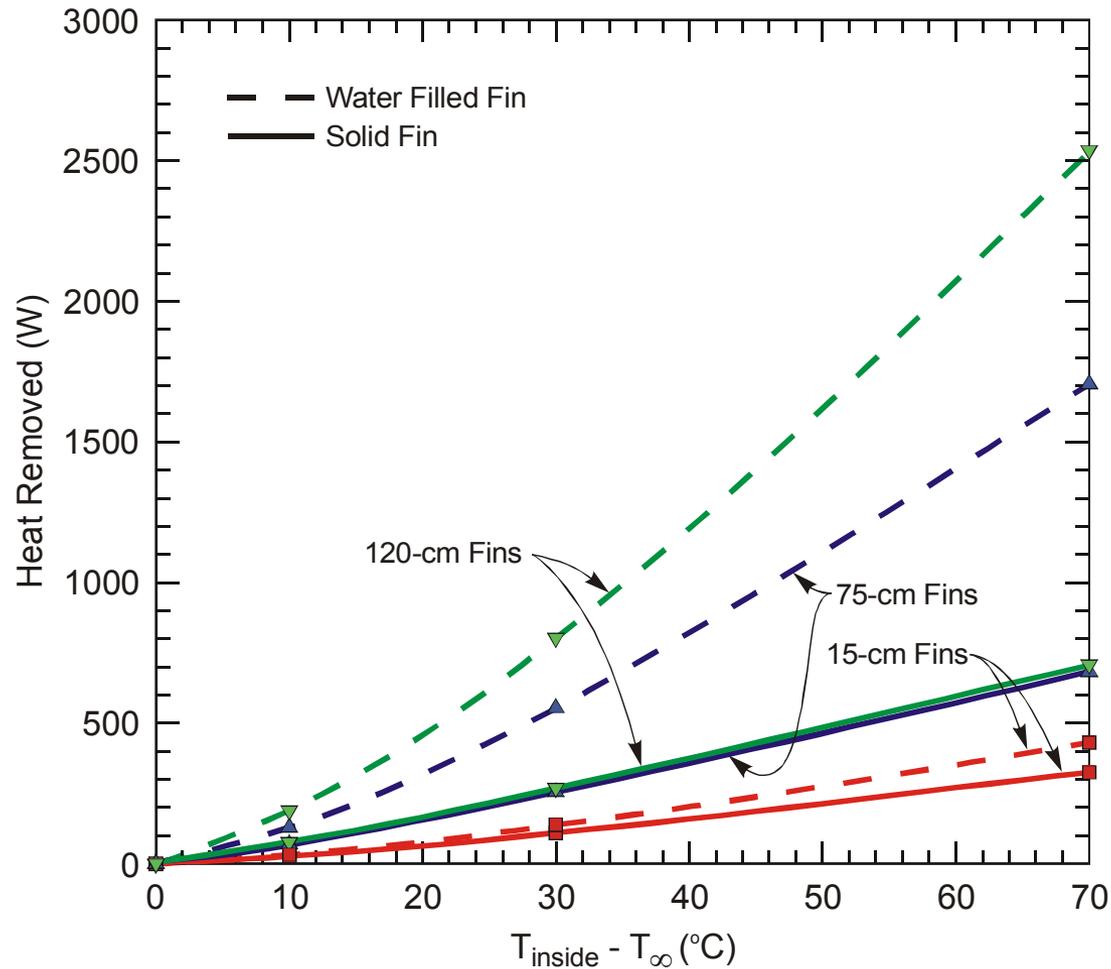
# Removable Liquid-Fin Cooling Jackets Are Being Examined as a Means to Enhance Cask Cooling

(Removal After Decay Heat Decreases and Before Repository Overpack Is Placed)



# Heat Rejection Per Fin Versus Temperature For Different Fin Depths

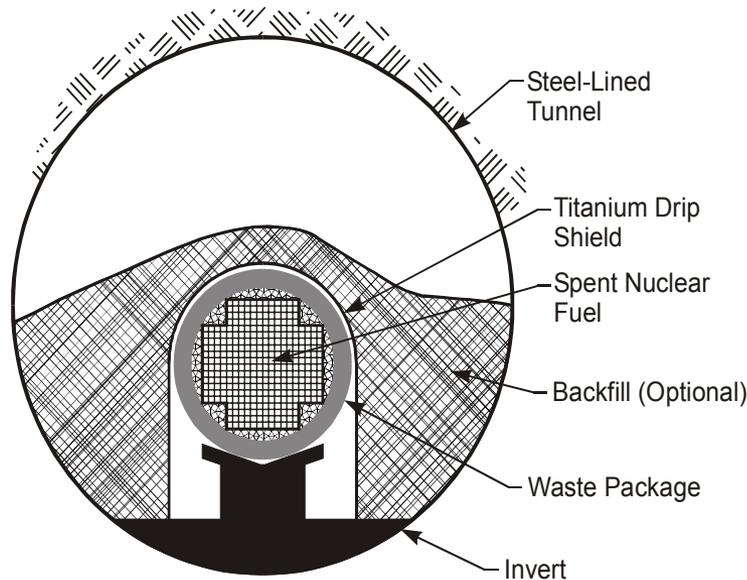
(38 kW for 21 SNF assembly cask and  $\Delta T = 30^\circ\text{C}$ )



# Liquid Fins Improve Performance

- **Large experience base**
  - Standard on electrical transformers
  - High reliability
  - Optimized cask fin design (smaller size) similar to transformer design
- **Related issues must be addressed**
  - Allowable time for repair if fin failure occurs
    - SNF temperature limited by clad degradation
    - Degradation dependent on time and temperature
  - Regulatory basis for liquid fins

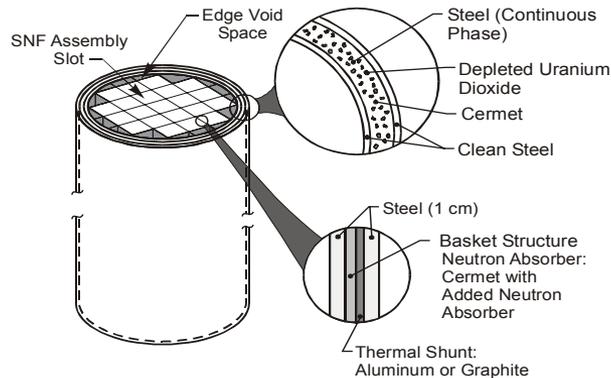
# Incentives: Multipurpose Shielded Casks Simplify Underground Operations (WP Placement, Inspection, Maintenance, and Backfill)



- **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**

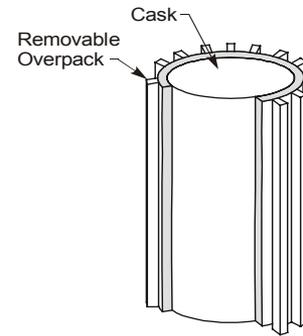
# Multipurpose Cask for Storage, Transport, and Disposal

## 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

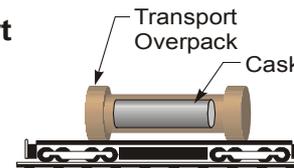
## Multipurpose Cask System



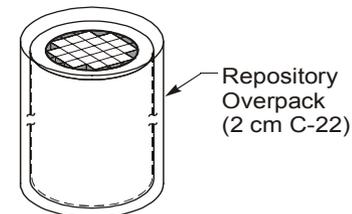
### Storage at Reactor With Overpack for Short-Cooled SNF

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

### Transport



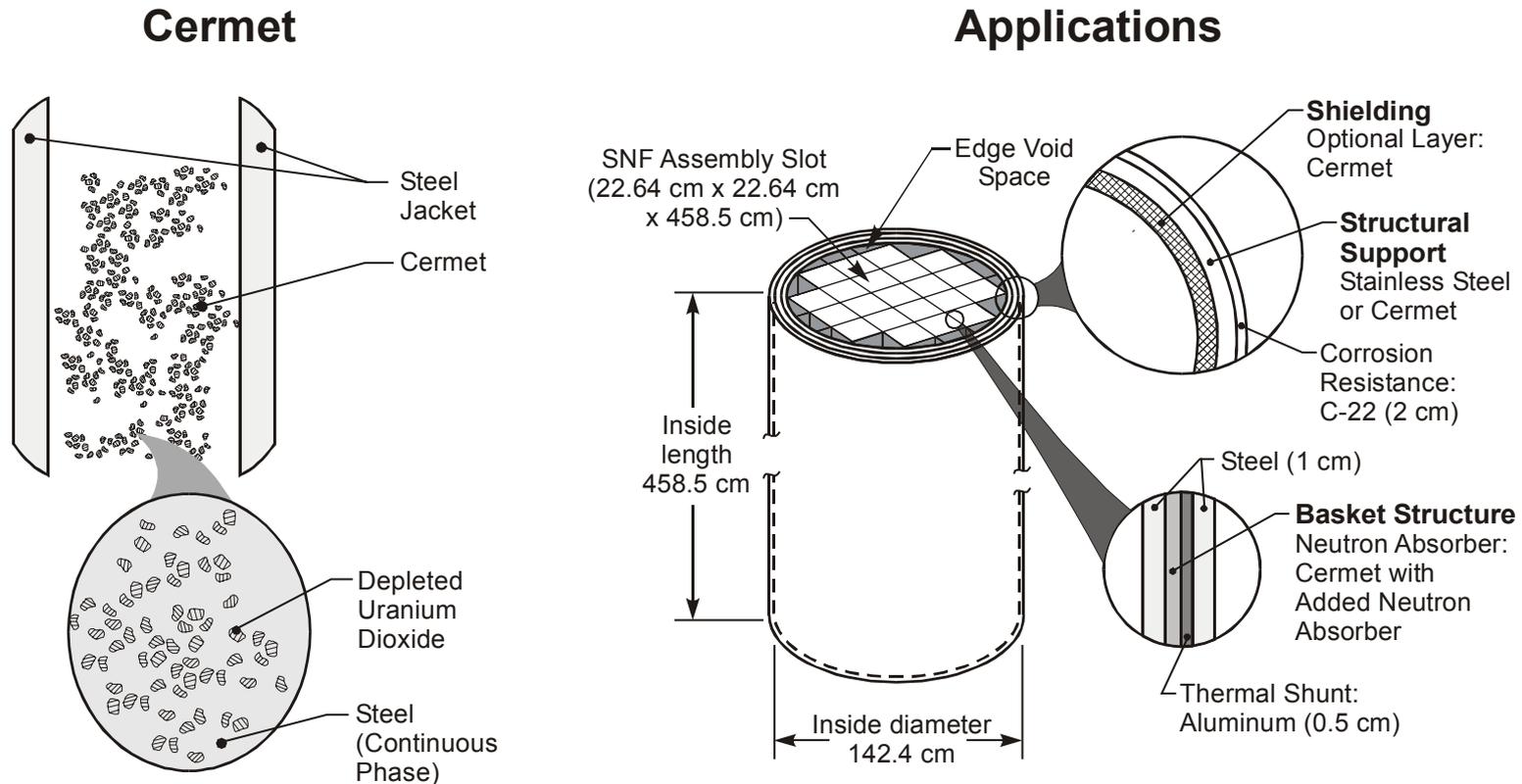
### Disposal at Repository With Overpack



# German GNS SNF Storage and Transport Cask on a Railcar

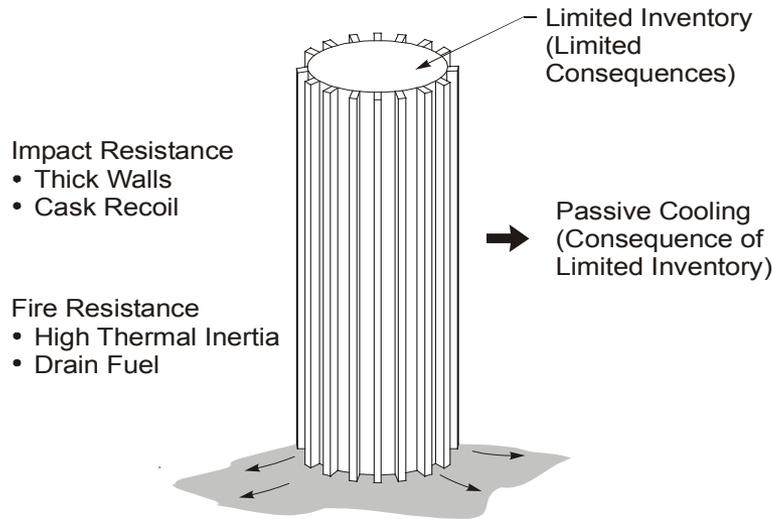


# Storage, Transport, and Repository Applications: Casks Can Be Constructed of a DUO<sub>2</sub>-Steel Cermet: 3-8 kg DU/kg SNF (Cermet Manufacturing Demonstrated: Cermets Were Used as Fuels In Some Early Reactors)



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

- **Hard/soft layers used in bank vaults and tank armor**
- **Non-uranium cermets are used in tank armor**
- **Cermet properties harden casks against assault**
  - DUO<sub>2</sub> hard layer
  - Steel soft ductile layer
- **Design trade-offs not well understood**



# **A Multipurpose Super Cask Is Proposed**

## **New Capability Based on the Use of New Cermet Materials**

- **Cermet definition: ceramics in metal matrix**
- **Metal matrix functions**
  - Strength
  - Integrity
  - Heat transfer
- **Ceramic component functions**
  - Gamma shielding ( $\text{DUO}_2$ , SiC,  $\text{Al}_2\text{O}_3$ )
  - Armor ( $\text{DUO}_2$ , SiC,  $\text{Al}_2\text{O}_3$ )
    - Traditional armor:  $\text{Al}_2\text{O}_3$  cermets (weight constraints, not a cask issue)
  - Neutron absorbers ( $\text{DUO}_2$ ,  $\text{Gd}_2\text{O}_3$ , SiC)