A DUO_2–Steel Cermet Multipurpose Super Cask

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Observations

- The LWR fuel cycle was designed for recycle of spent nuclear fuel (SNF) and has evolved into a once-through fuel cycle
- An LWR fuel cycle designed as a once-through system would be substantially 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 needed

Outline

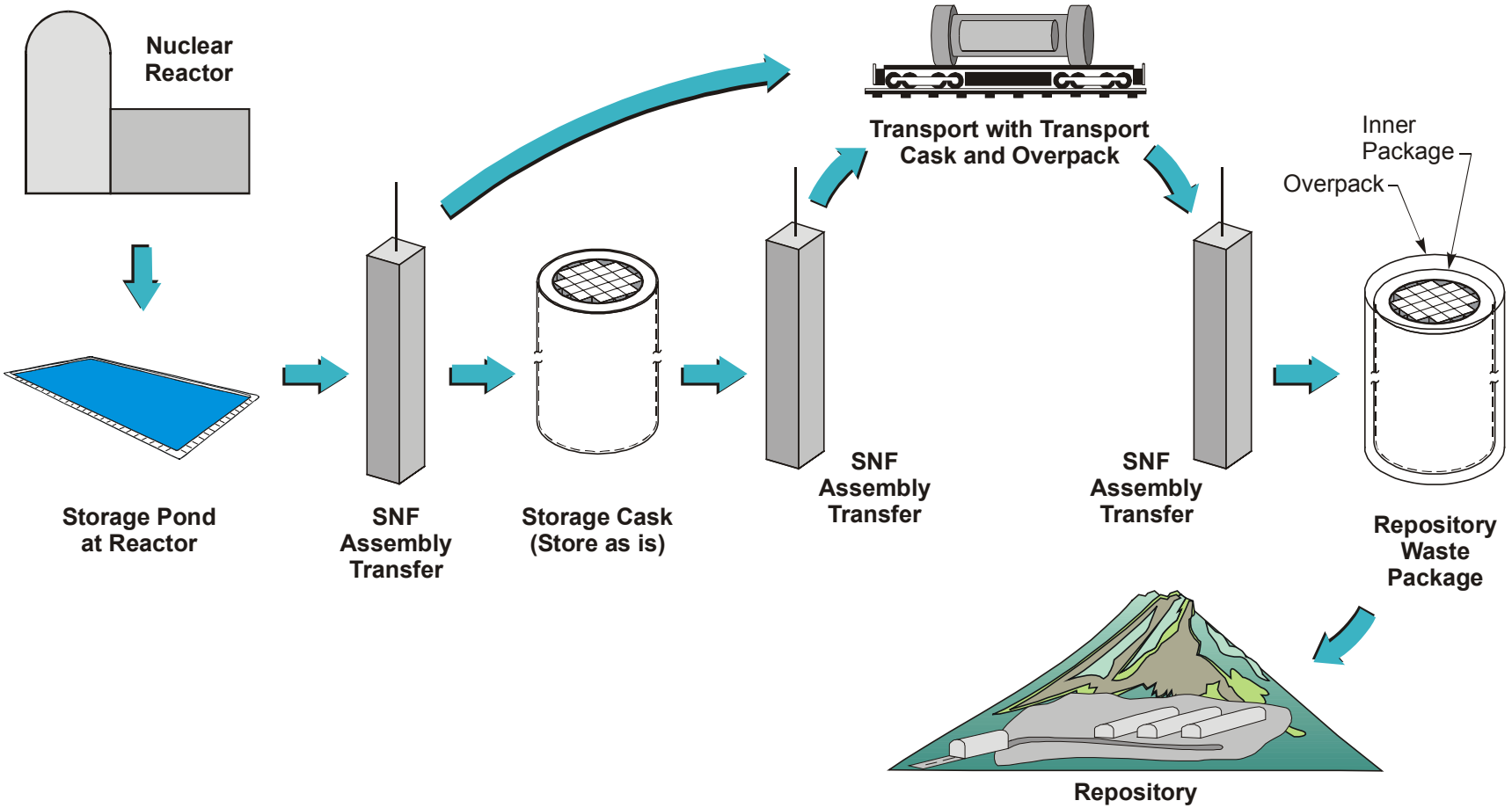
- Traditional Spent Nuclear Fuel (SNF) Management Strategy
- An Advance Once-Through SNF System
- Multipurpose Cask System
- Cask Requirements and Design
- Cooling Overpack
- Manufacturing Technologies
- Conclusions

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

Traditional Spent Nuclear Fuel (SNF) Management Strategy

- A nuclear power reactor generates 30 tons of highly radioactive SNF (waste) per year
- SNF is stored in pools or casks
  - Most SNF is stored in pools
- SNF will be shipped in metal transport casks (~10 tons uranium per cask) to an underground repository for disposal
- Limited number of transport casks are required

Traditional Approaches to SNF Management Imply Multiple Handling of Individual Assemblies



An Advance Once-Through Fuel Cycle

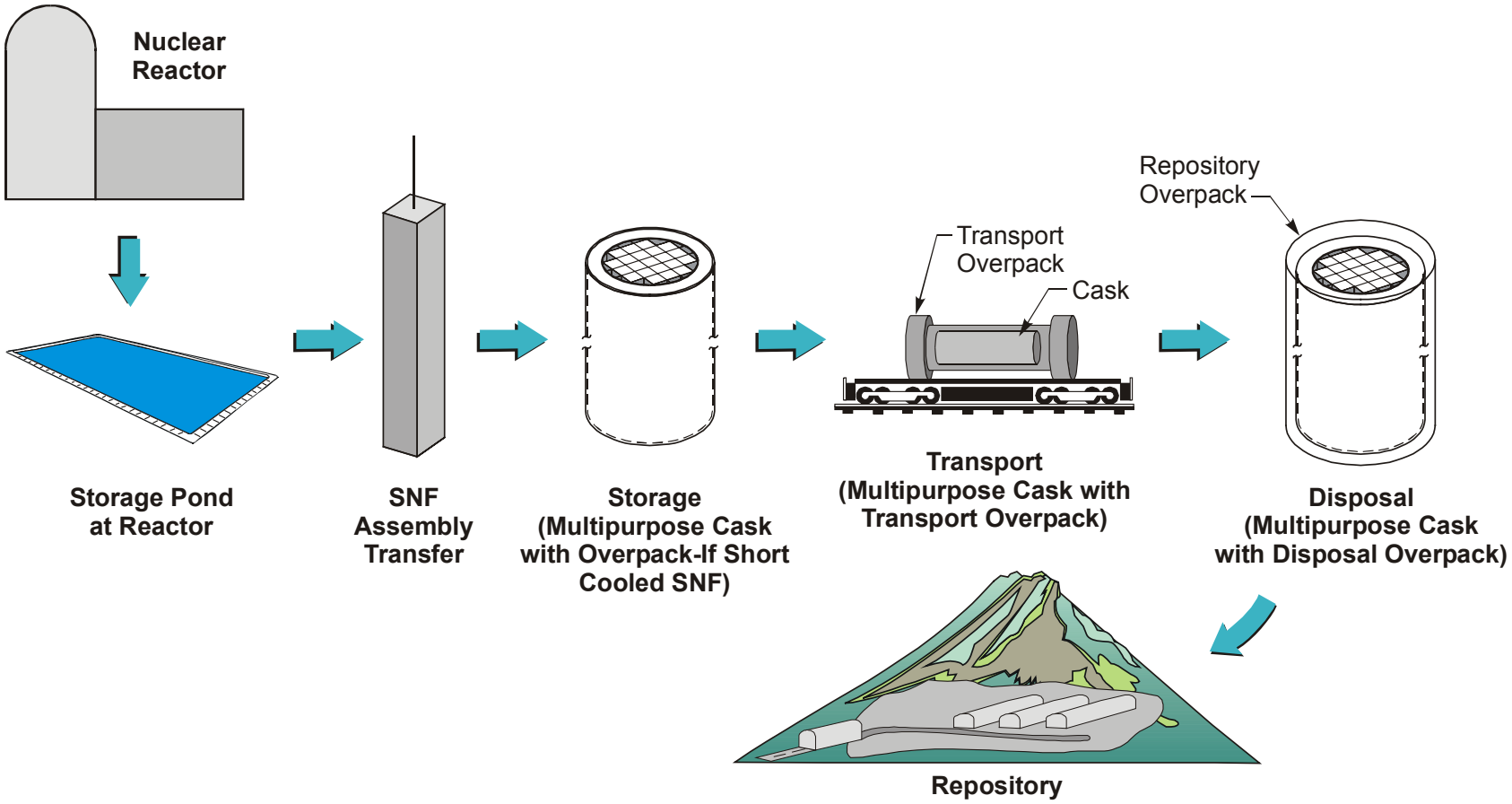
Current System Used Worldwide Has Significant Weaknesses

- **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
- **System evolved without strong emphasis on security or safeguards**
  - Multiple handling of SNF
  - High dependence on active security and safeguards
  - Diversion and theft primarily controlled by labor-intensive activities and administrative procedures

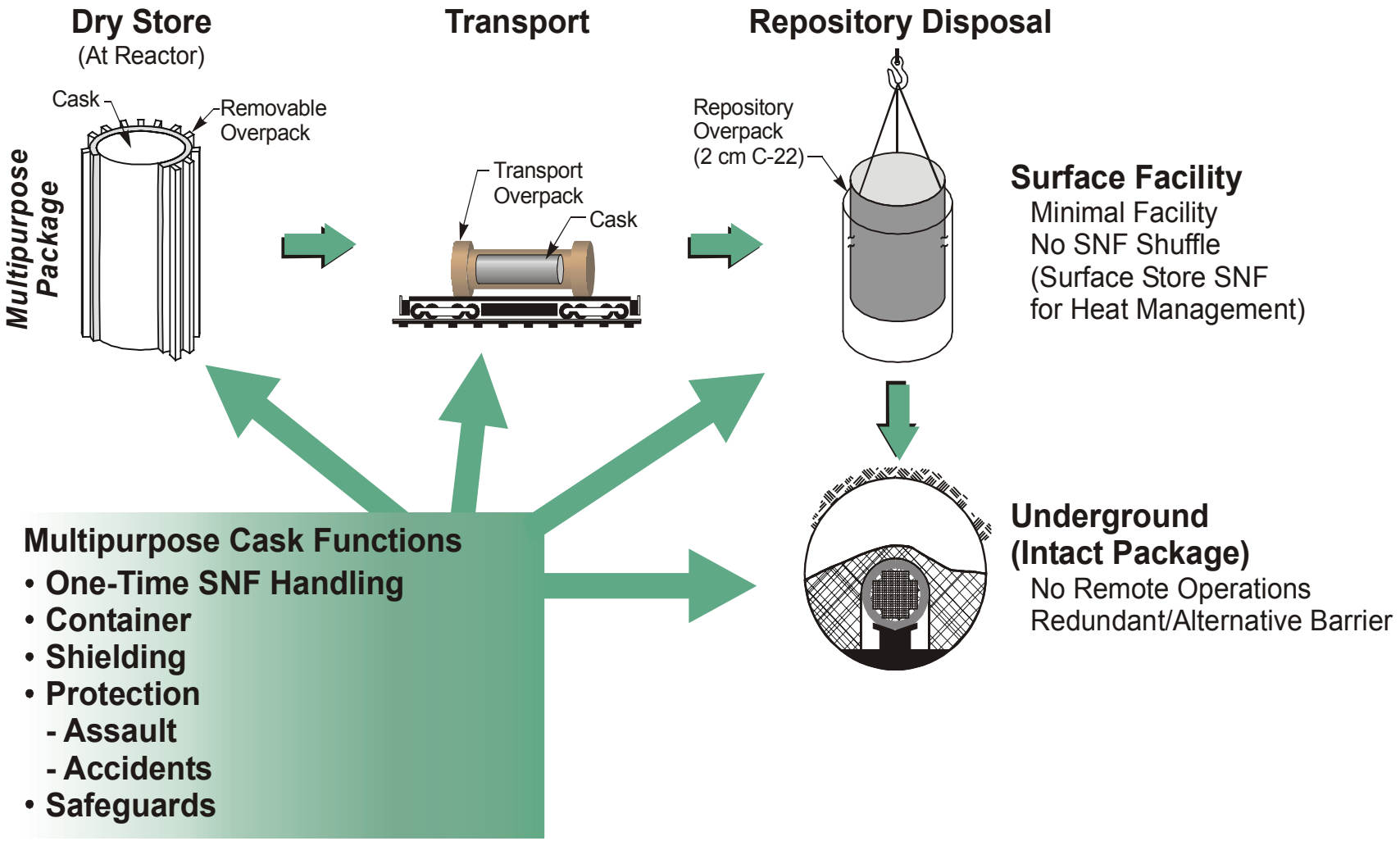
A New Once-Through SNF System Is Proposed To Accomplish Two Objectives

- **Minimize SNF handling**
  - **Handling operations are a weak link**
  - **In the new 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

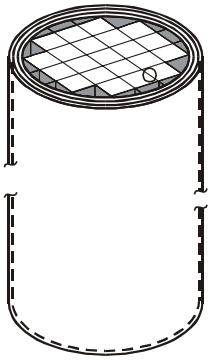


Multipurpose Cask System to Minimize Handling



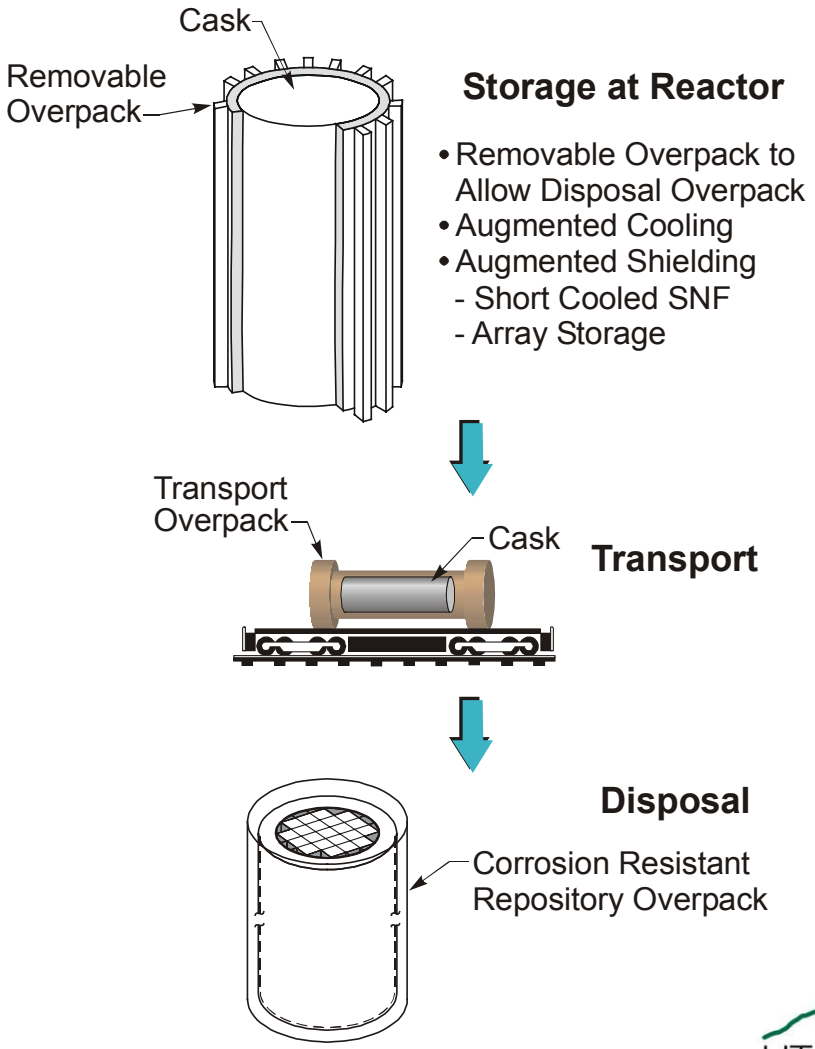
Multipurpose Cask System Use Overpacks to Address Variable Requirements

Multipurpose Cask



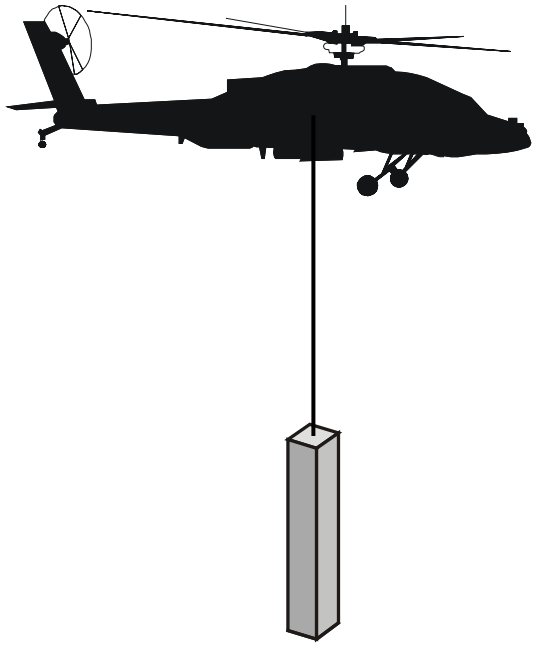
- Radiation Shielding
- Accident/Assault Protection: Multilayer Cermet
- Safeguards and Theft Resistance
- Decay Heat Removal

Multipurpose Cask System



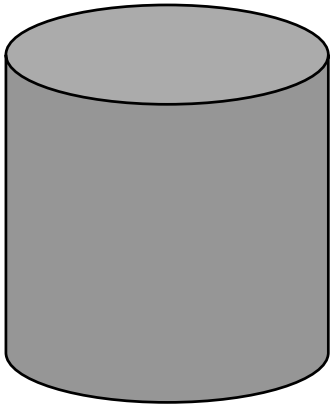
Multipurpose Casks By Their Characteristics Provide Protection Against Theft Or Diversion

Fuel Assembly



Low weight (~1 ton), small size

Multipurpose Cask



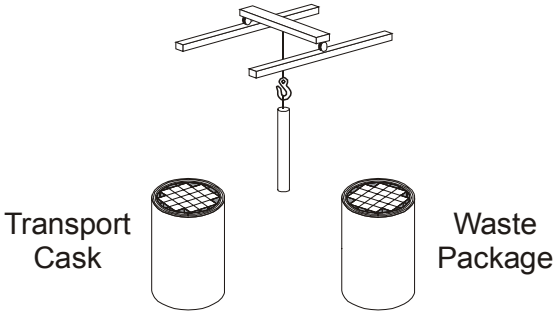
Large weight (>70 tons), large size, visible from orbit

If Casks Are Used for SNF Storage, a Strong Incentive Exists to Use the Multipurpose Casks for the Entire System

- Cask loaded at reactor
- Cask used for SNF storage
- Cask used for SNF transportation
- Cask used for SNF disposal

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

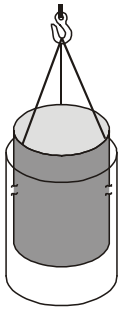
Current System



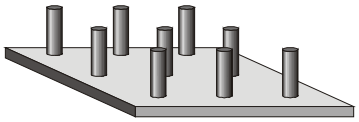
Remote Transfer of SNF

Adjusting Waste Package Heat Load for the Repository

Multipurpose Cask System



Addition of Overpack



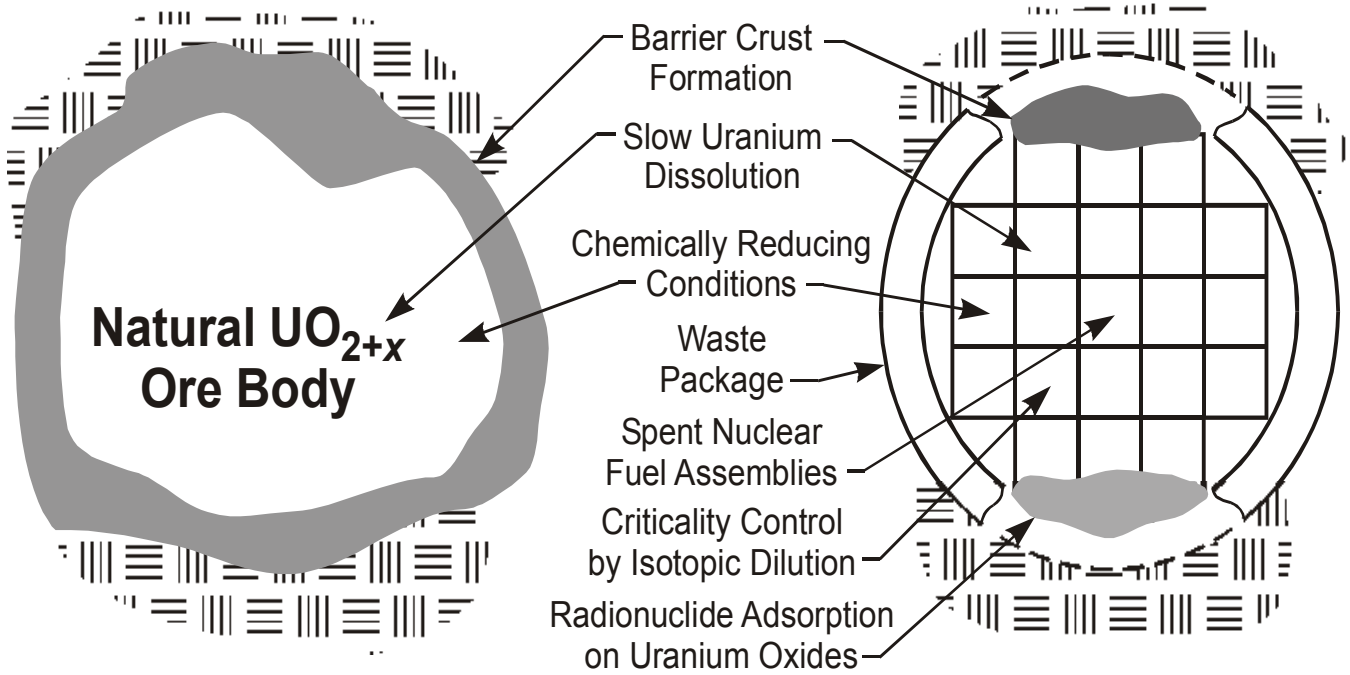
Surface Storage Until Repository Acceptable Heat Load

Incentives Exist to Use Casks Made of Depleted Uranium Dioxide (DUO_2) Embedded in Steel

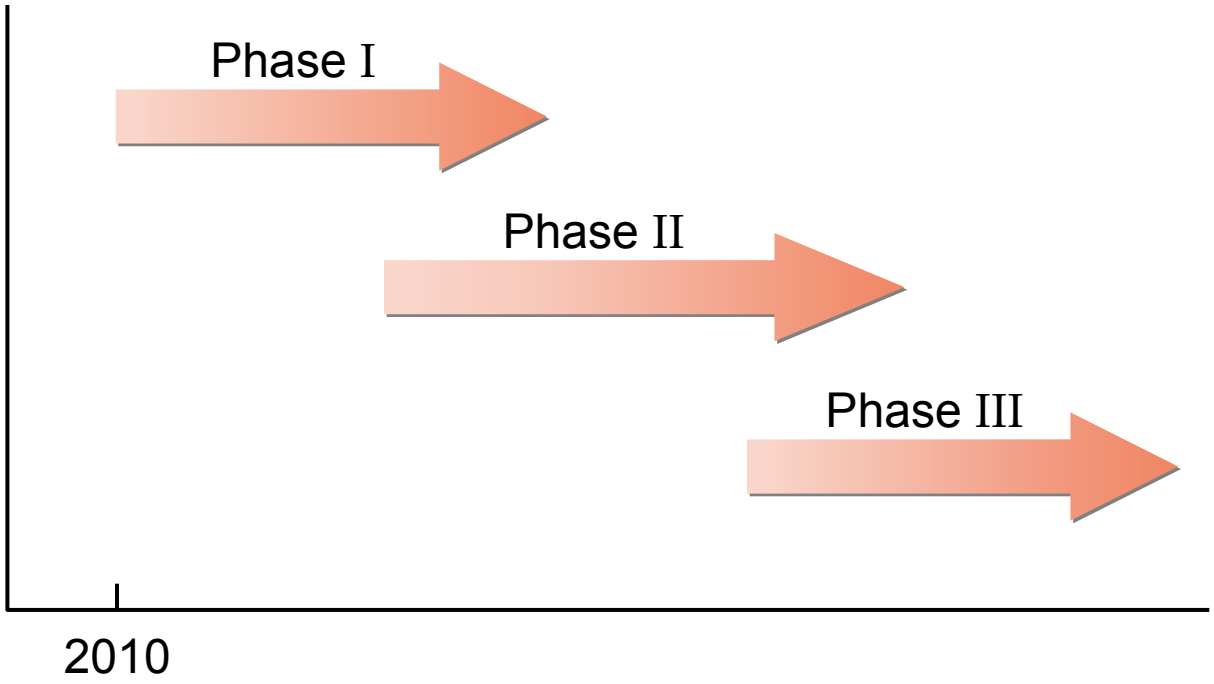
- Improves performance of multipurpose casks
  - Better radiation shielding (higher capacity casks)
  - Improved performance in repository
  - Armor capabilities (cermets used in tank armor)
- Disposes of DU (500,000-ton surplus)

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)



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



Cask Requirements and Design

Multipurpose Cask Requirements

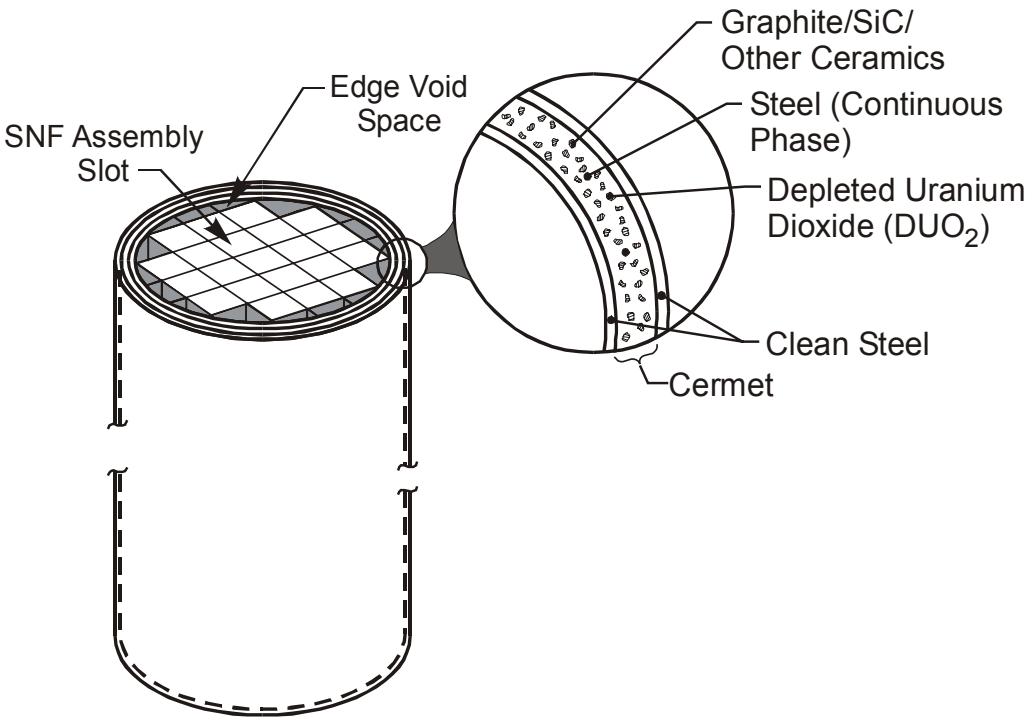
- Gamma and neutron shielding
- Protection against accidents and assault
- Decay-heat removal
- Compatible with storage, transport, and disposal
- Economic (large SNF capacity within weight and mass limits)

A Multipurpose Super Cask Is Proposed

New Capability Based on the Use of New Cermet Materials

- Cermets (ceramics in metal matrix)
- Metal matrix functions
  - Strength
  - Integrity
  - Heat transfer
- Ceramic component functions
  - Gamma shielding (DUO_2, SiC, Al_2O_3)
  - Armor (DUO_2, SiC, Al_2O_3)
    - Traditional armor: Al_2O_3 cermets (weight constraints, not a cask issue)
  - Neutron absorbers (DUO_2, Gd_2O_3, SiC)

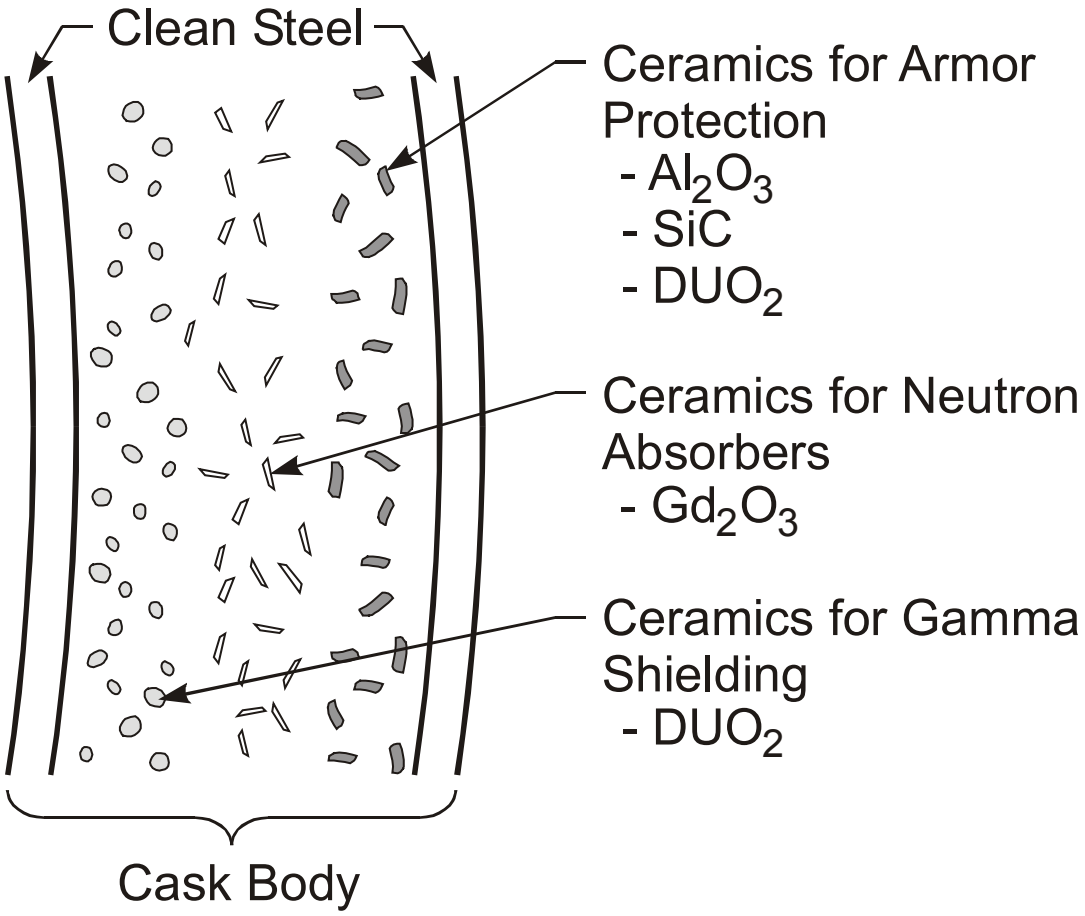
Cermets (Ceramics in Metal Matrix) Allow Optimization of Cask Performance Within a Monolithic Form



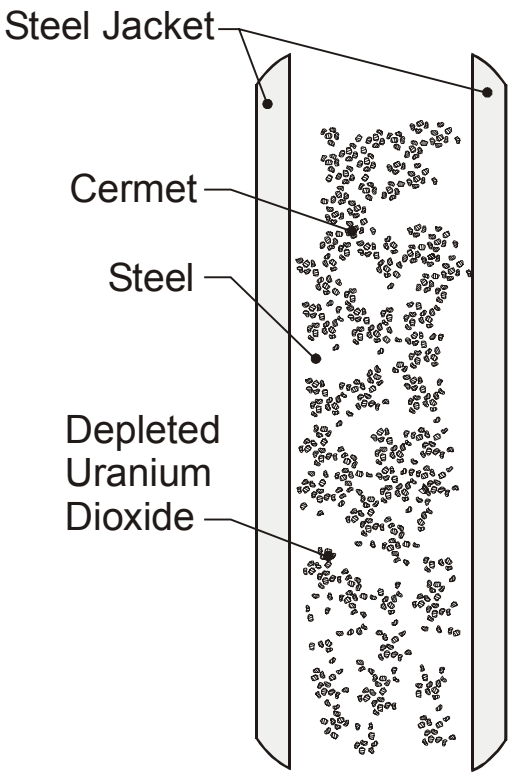
Functions

- 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

Variable Compositions Across the Cermet May be Used for a Super Cask

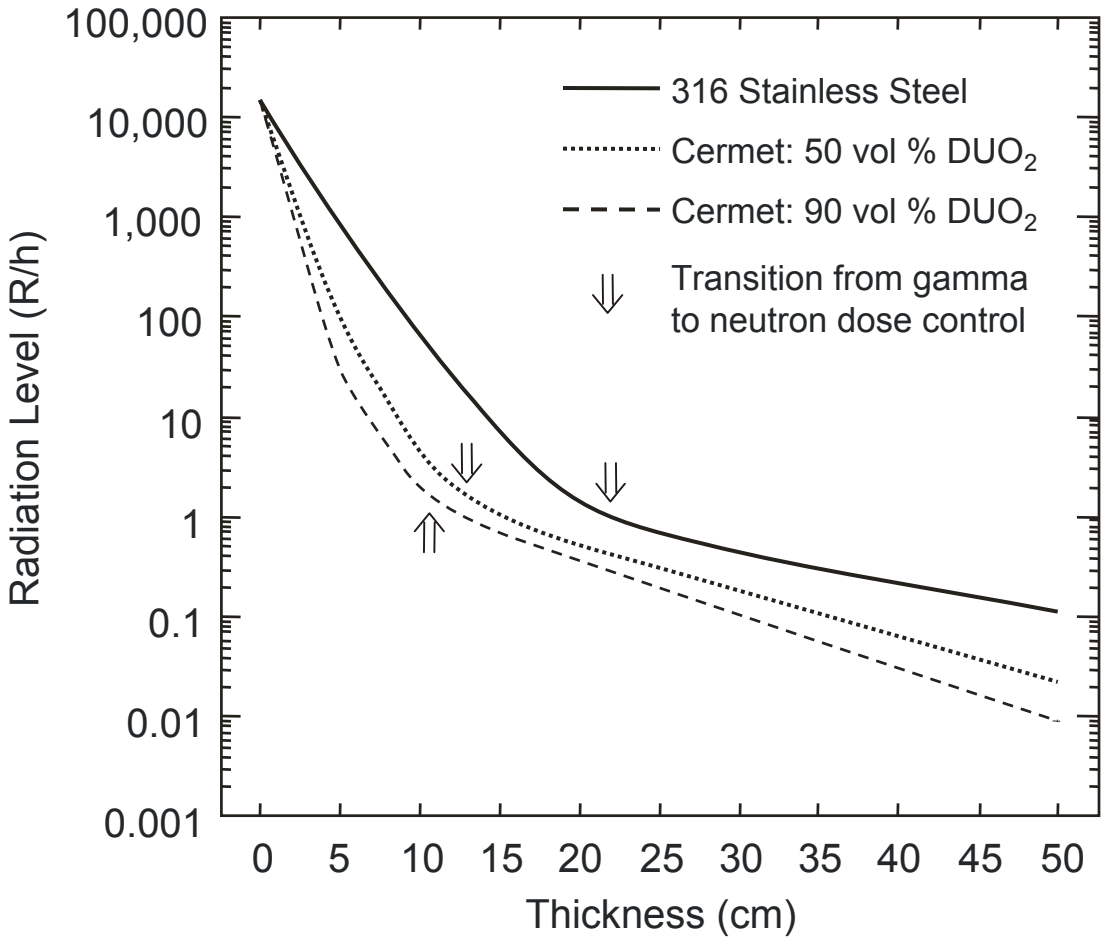


DUO_2–Steel Cermets Are Excellent Shielding Materials with Some Unique Capabilities



- 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 SNF casks for a given weight limit
- Cermets may be the best shielding material
- Other candidates 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)

Military Armor Made from Cermets

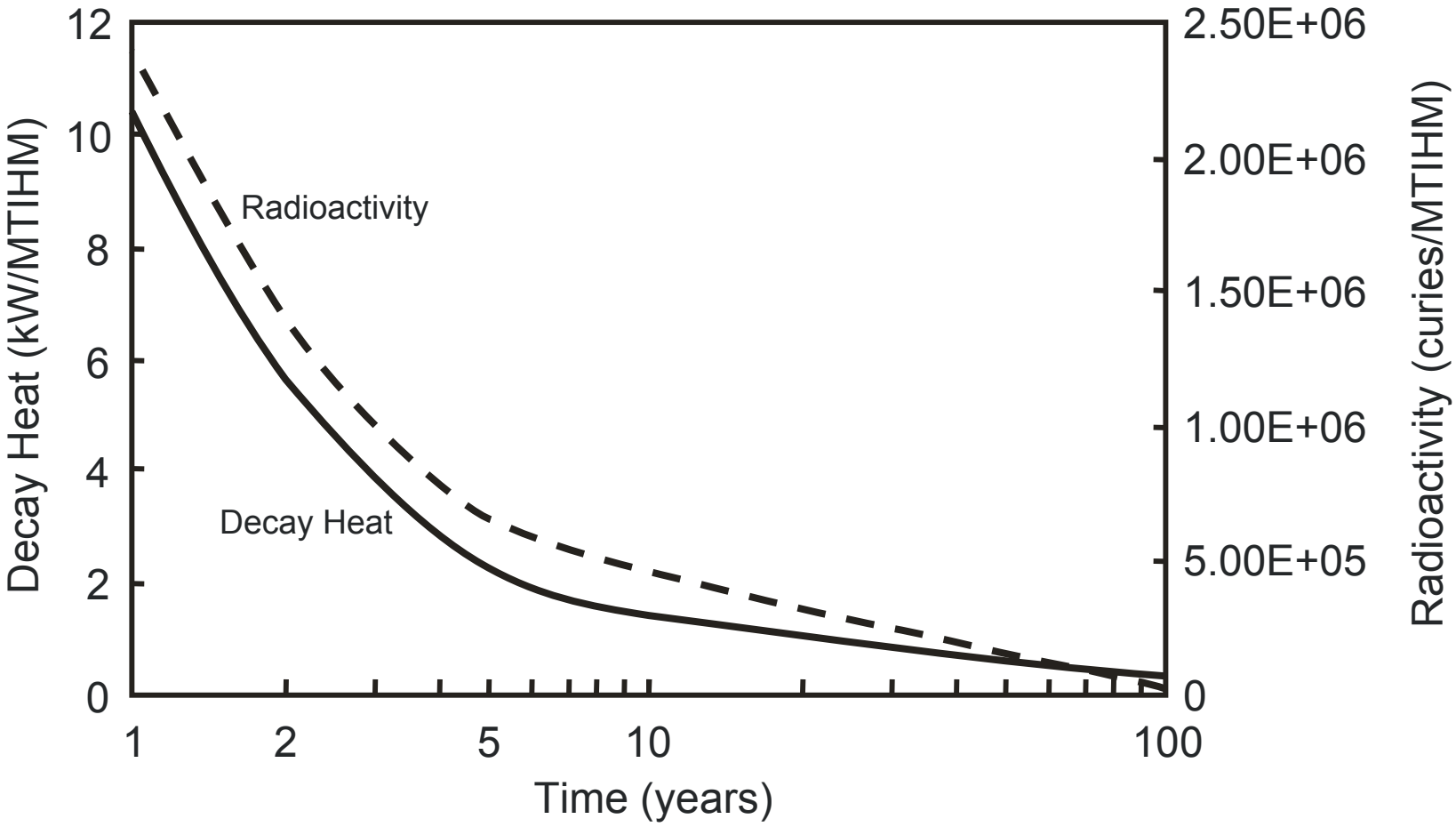
- Armor is used for (tanks, bank vaults, etc.)
  - Composite armor is now generally used
    - A single material is easy to defeat
  - Modern armor has two components
    - Hard material (ceramics)
    - Strong ductile materials (metals)
- ORNL is working with Lawrence Livermore National Laboratory in this area

Cask Cooling

Cermets Are More Attractive If Casks Can Accept High Heat Loads

- Improved shielding allows higher capacity for same weight cask
- Higher capacity is possible only if SNF temperatures can be limited
- A program has been established to examine enhanced cooling options
  - External liquid-cooled fins
  - New high-conductivity basket materials

Cask Cooling Is a Short-Term Problem

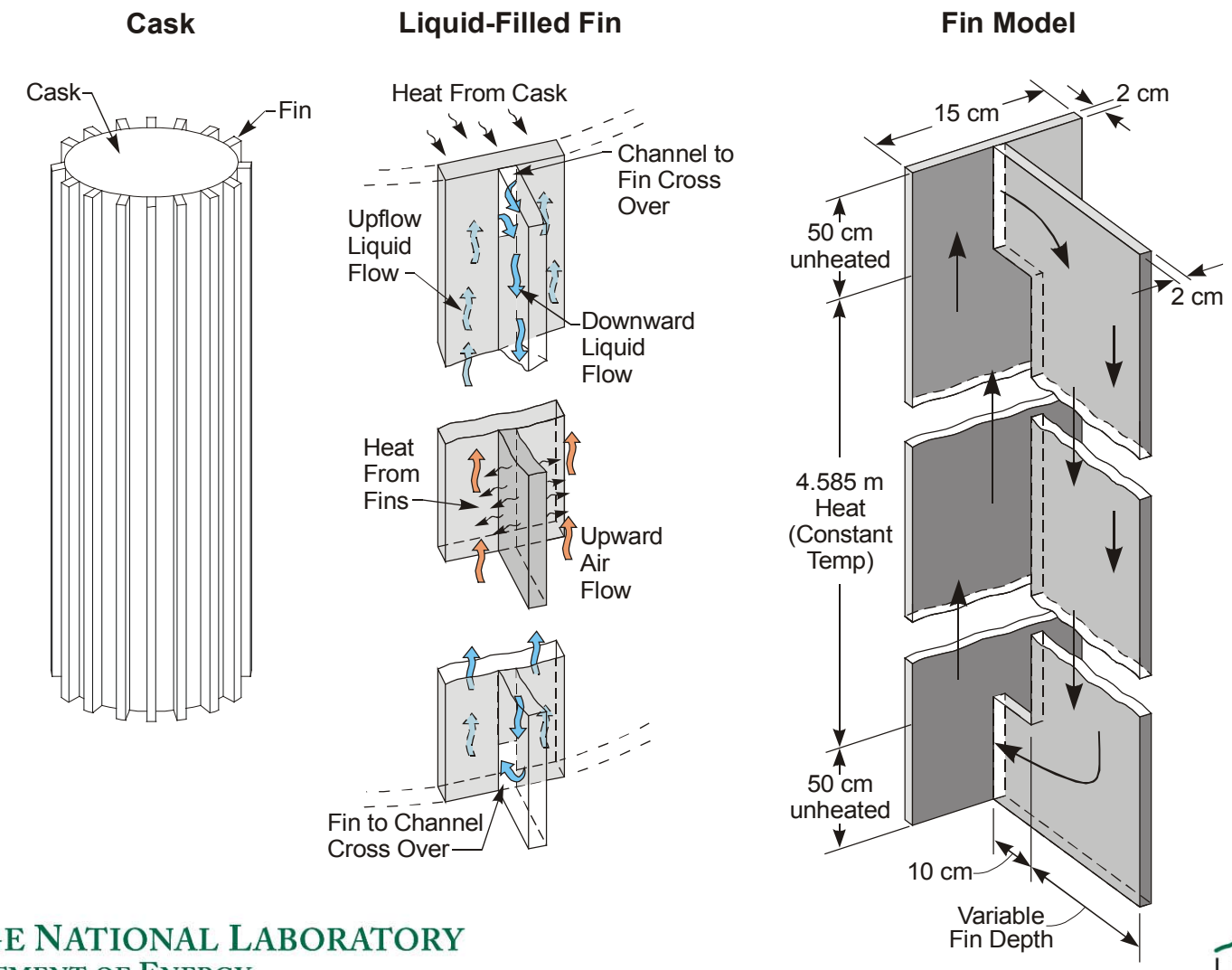


Graphite Is Being Examined To Improve Basket Heat Removal and Neutron Shielding

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

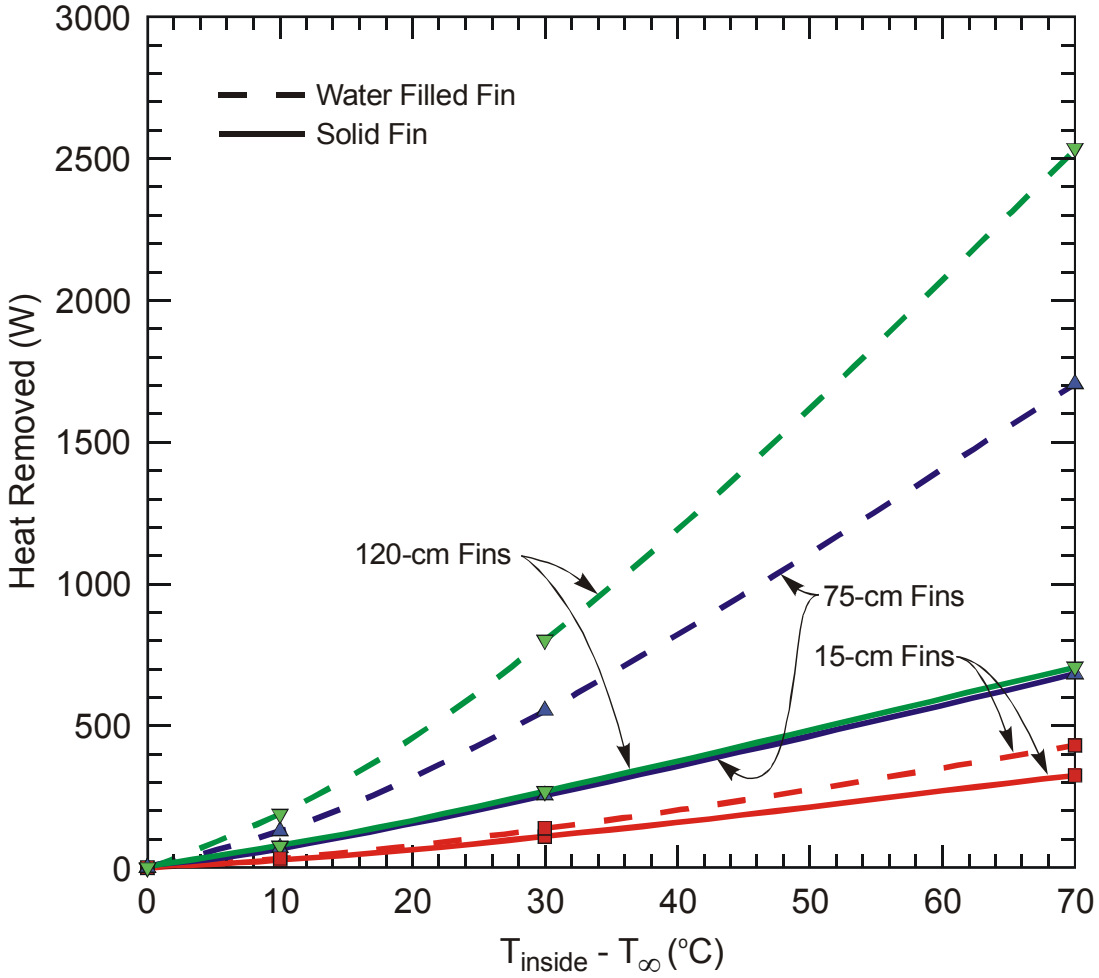
Removable Liquid-Fin Cooling Jackets Are Being Examined as a Means to Enhance Cask Cooling

(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 ∆T = 30ºC)



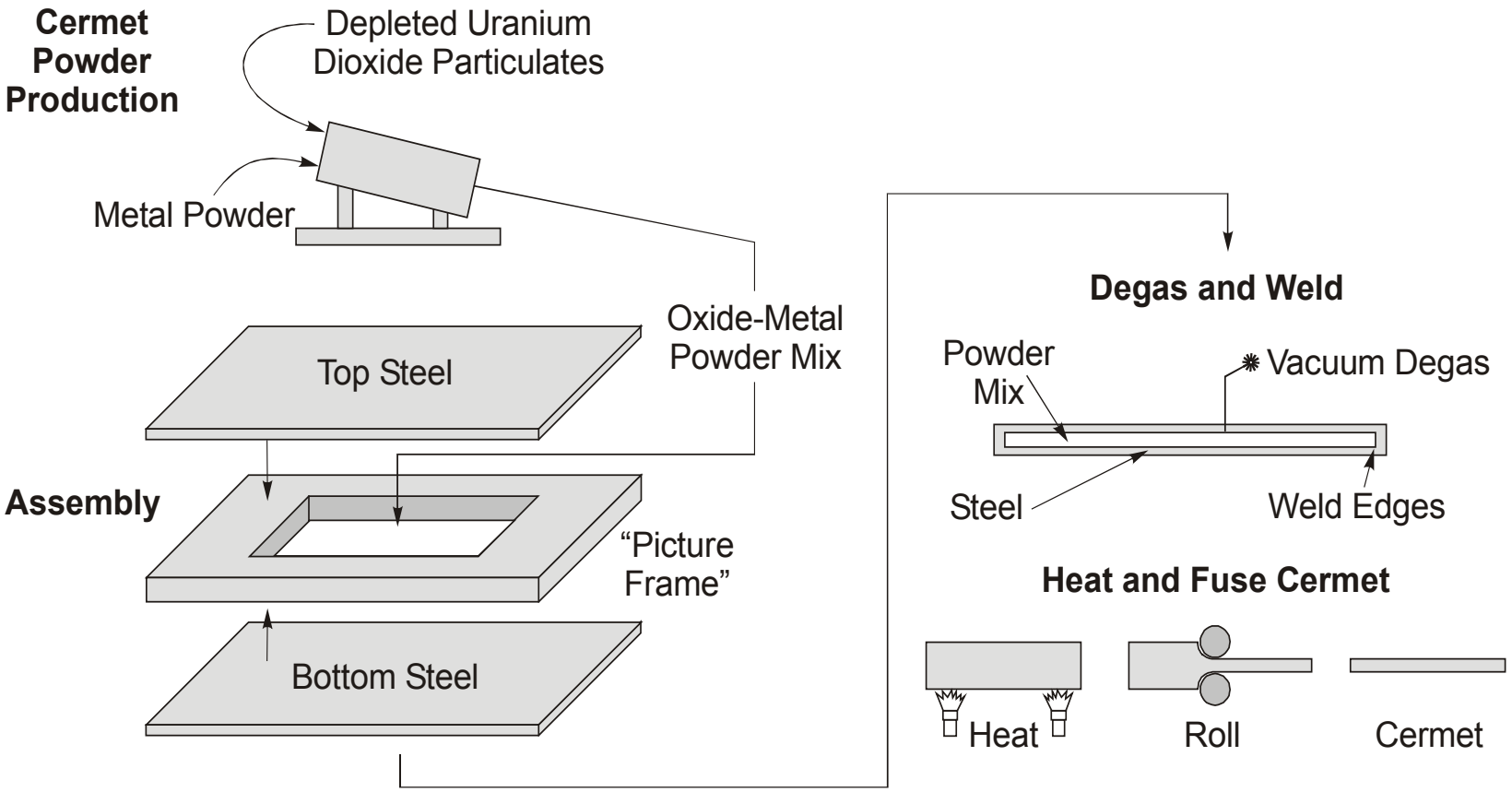
Liquid Fins Improve Performance

- 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

Manufacturing Technologies

"Picture-Frame" Method for Cermet Production

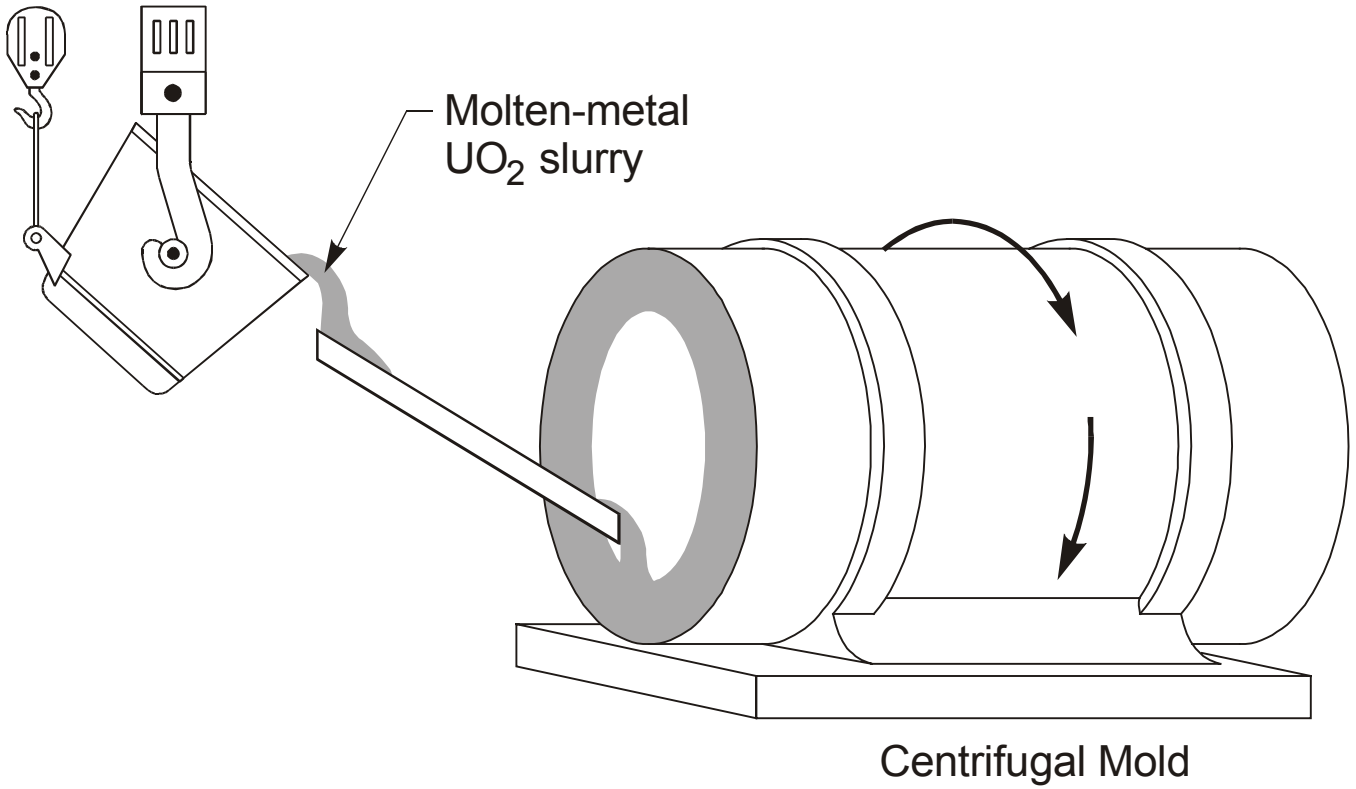
(Used for Some Nuclear Reactor Fuels and Some Nonnuclear Applications)



Centrifugal Casting May Allow Low-Cost Fabrication of Cask Body

- Some nonnuclear cermets are manufactured by molten-metal ceramic-particulate slurry casting with solid ceramic particles
- Centrifugal casting is used for sewer pipes and other low-cost products
- Multi-layer construction possible
- 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; Vertical Casting Likely for SNF cask)



Several New Methods Have the Potential to Significantly Reduce Cermet Cask Manufacturing Costs

- "Business Confidential"
- Public disclosure by October 2002
  - Patent filings

Economics Dependent On Several Factors

- Cermet performance (larger-capacity casks within same mass and size envelope)
- Cost of cask production cost
  - Work under way on new production methods
  - Goal: to achieve lower fabrication costs than those obtained via current methods
- DUO_2 credits or costs

Conclusions

- Cermets have the potential to create a high-integrity Super Cask with outstanding performance
- DUO_2 cermets have radiation shielding and repository performance advantages
- Potential exists for low-cost fabrication methods