A New Method for Manufacturing Depleted Uranium Dioxide–Steel Cermet Casks For SNF and Radioactive Wastes

Dr. Charles W. Forsberg
Dr. Vinod Sikka

Depleted Uranium Users Conference
American Society of Manufacturing
Knoxville, TN
April 20-22, 2004

Oak Ridge National Laboratory*
P.O. Box 2008; Oak Ridge, TN 37831-6165
Tel: (865) 574-6783; E-mail: forsbergcw@ornl.gov

*Managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725. The submitted manuscript has been authored by a contractor of the U.S. Government under contract DE-AC05-00OR22725. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes. File name: Cermet_ppt: DUUser.Conf2004

Nuclear Reactors Produce Spent Nuclear Fuel (SNF) Requiring Storage, Transportation, and Disposal

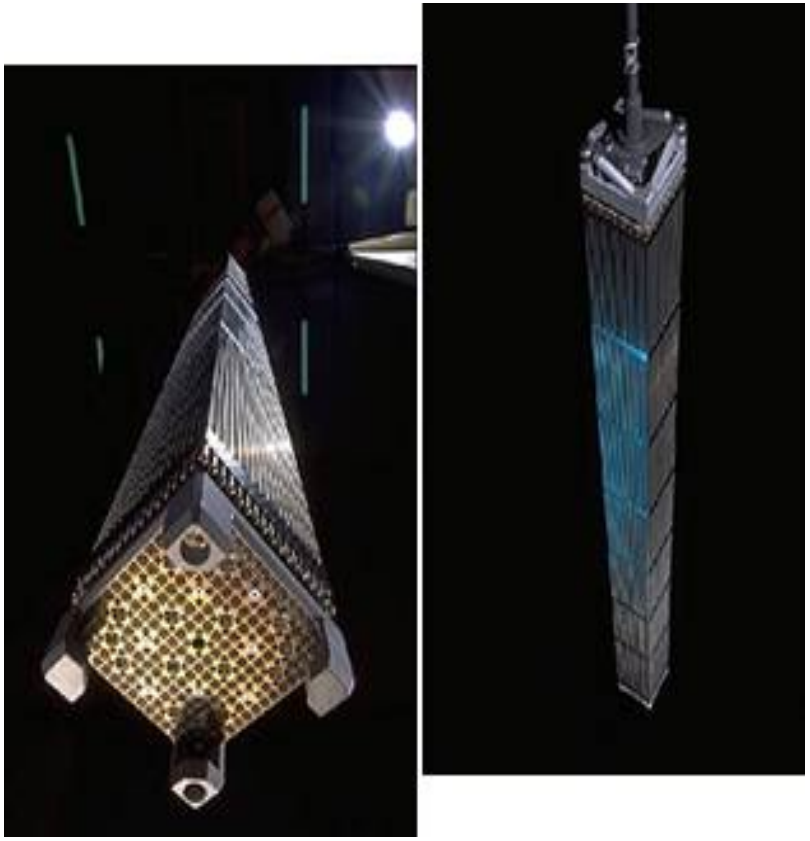
SNF Cask Requirements

Provide Radiation Shielding

Facilitate Removal of Decay Heat

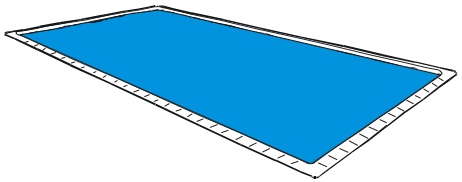
Protect Against Theft

Protect Against Accidents

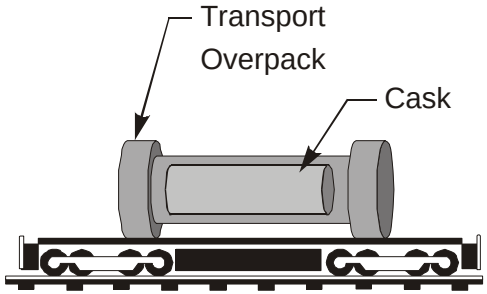


Typical SNF Casks Weigh About 100 Tons
(German GNS SNF Storage and Transport Cask on a Railcar)

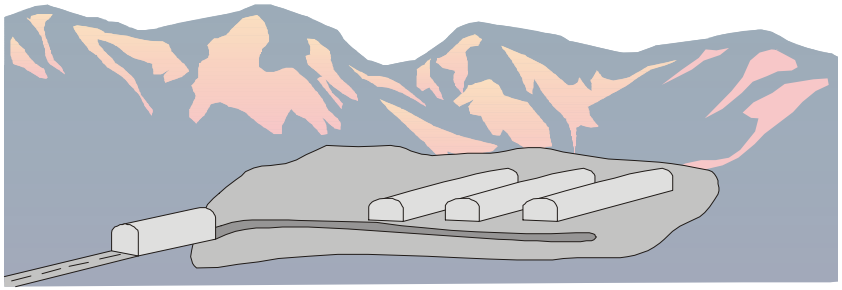
There Is the Potential for Major Growth in SNF Cask Demand



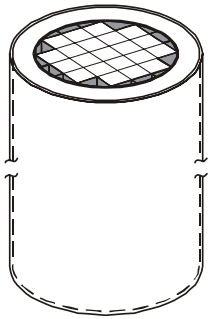
Limited SNF Pool Storage at Reactors



Transport to Repository



Cask Storage to Age SNF; Disposal of SNF

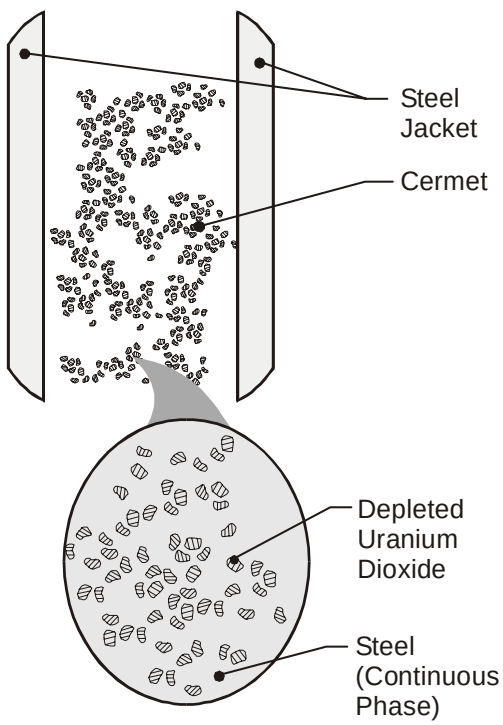


Improved Security Relative To Other Storage Options

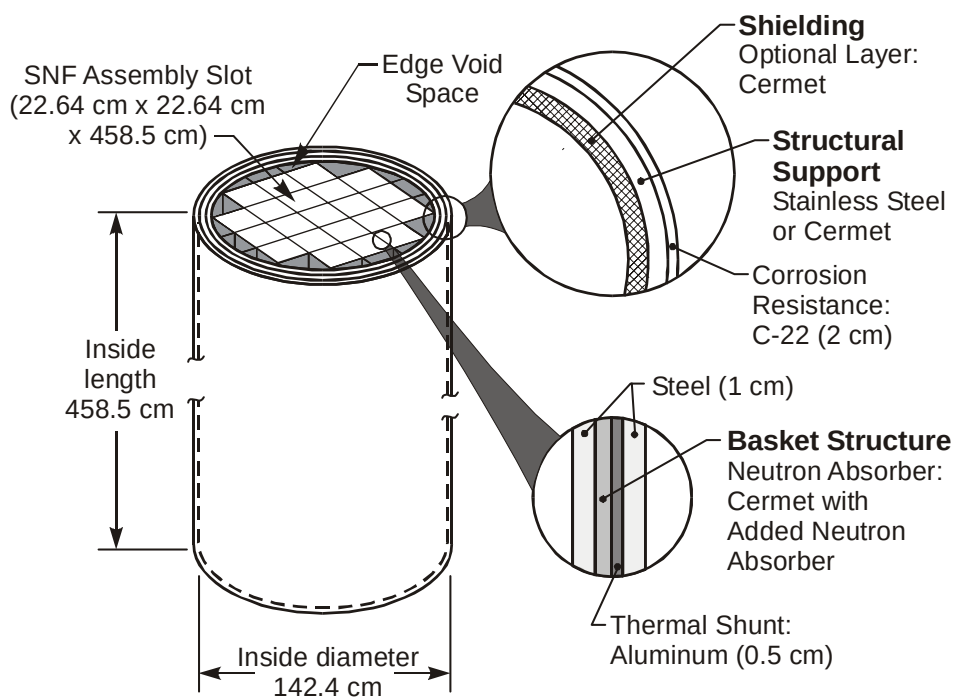
ORNL Is Investigating DUO_2-Steel Cermet SNF Casks

(Storage, Transport, Disposal, and Multipurpose)

Cermet



Applications



Why Cermet Casks?

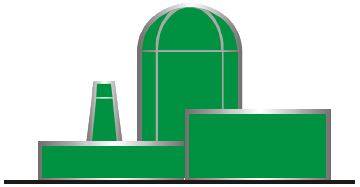
Cermets Are Traditionally Used In Physically Demanding Applications

(However, They Are Extremely Difficult to Weld and Hard to Form)

Main Battle Tank Armor

Brake Shoes

Cutting Tools



Test Reactors
(UO_2-Steel Cermets)

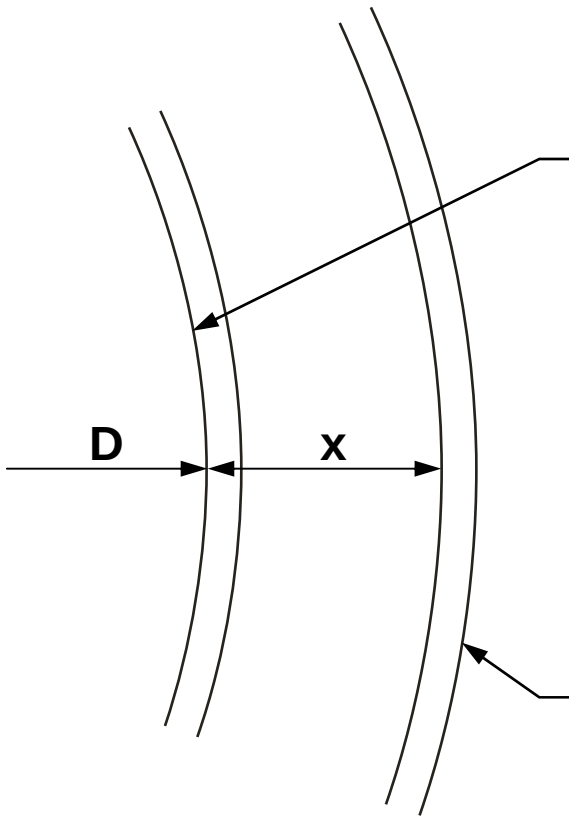
Cermets combine the best properties of metals and ceramics

- Metals
  - Ductility
  - Thermal conductivity
  - Strength
- Ceramics
  - Shielding
  - Hardness (Armor)
  - Other

Limits on Cask Weight Control Cask Capacity and Strongly Impact Economics

- Facility and transport (rail) constraints limit total cask weight
- Strong incentives exist to maximize the number of SNF assemblies per cask
  - Cask cost is a weak function of cask capacity; bigger casks have lower costs per SNF assembly
  - Operations costs primarily dependent upon the number of casks handled

High-Density, Minimum-Thickness Shielding Minimizes Total Cask Weight



Volume (First Centimeter of Shielding)

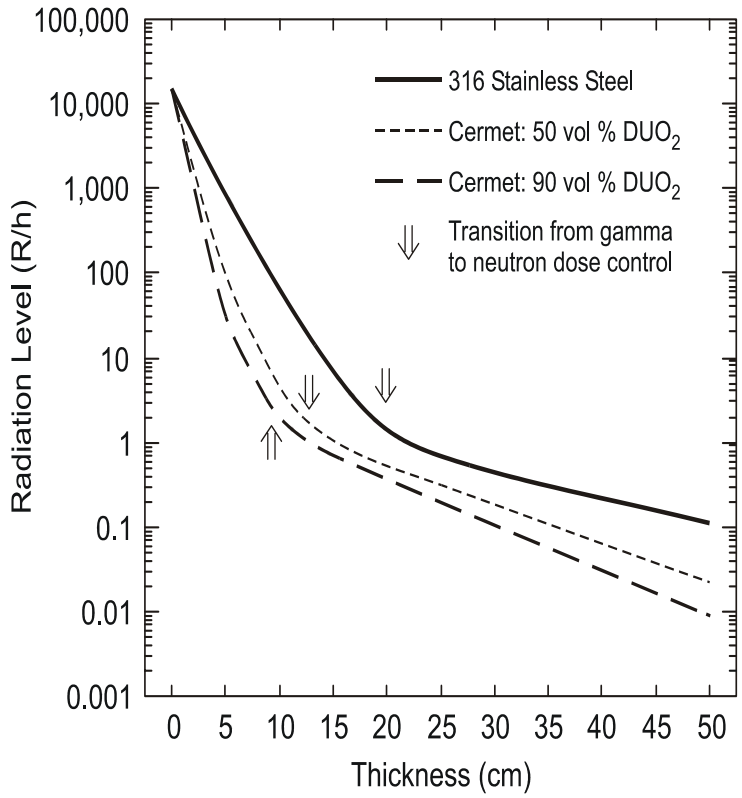
$$= \pi\, D\, H\, (1)$$

Height *Thickness*

Volume (x^{th} Centimeter of Shielding)

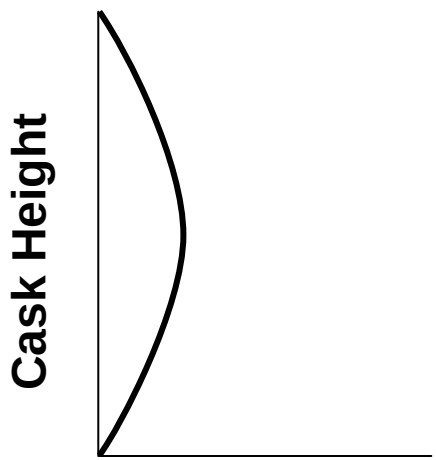
$$= \pi\, (D + 2x)\, H\, (1)$$

DUO_2-Steel Cermets Are a Superior Shielding Material for Casks

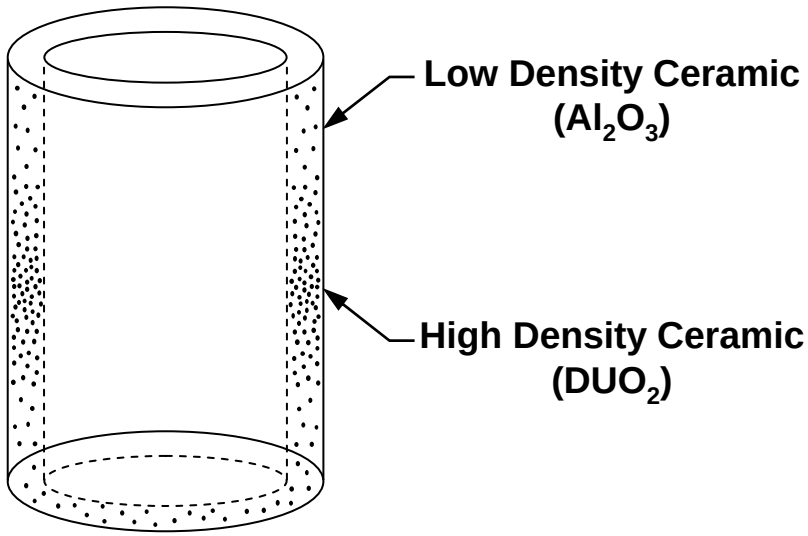


- **Thinner shielding**
- **Avoids other constraints**
  - **No concrete (not allowed in repository)**
  - **No RCRA metals (lead)**
  - **No organics**
  - **Cost constraints (no tungsten)**
  - **No reactive metals (uranium metal)**

Cask Weight Can Be Reduced with Variable Density Cermet Shielding



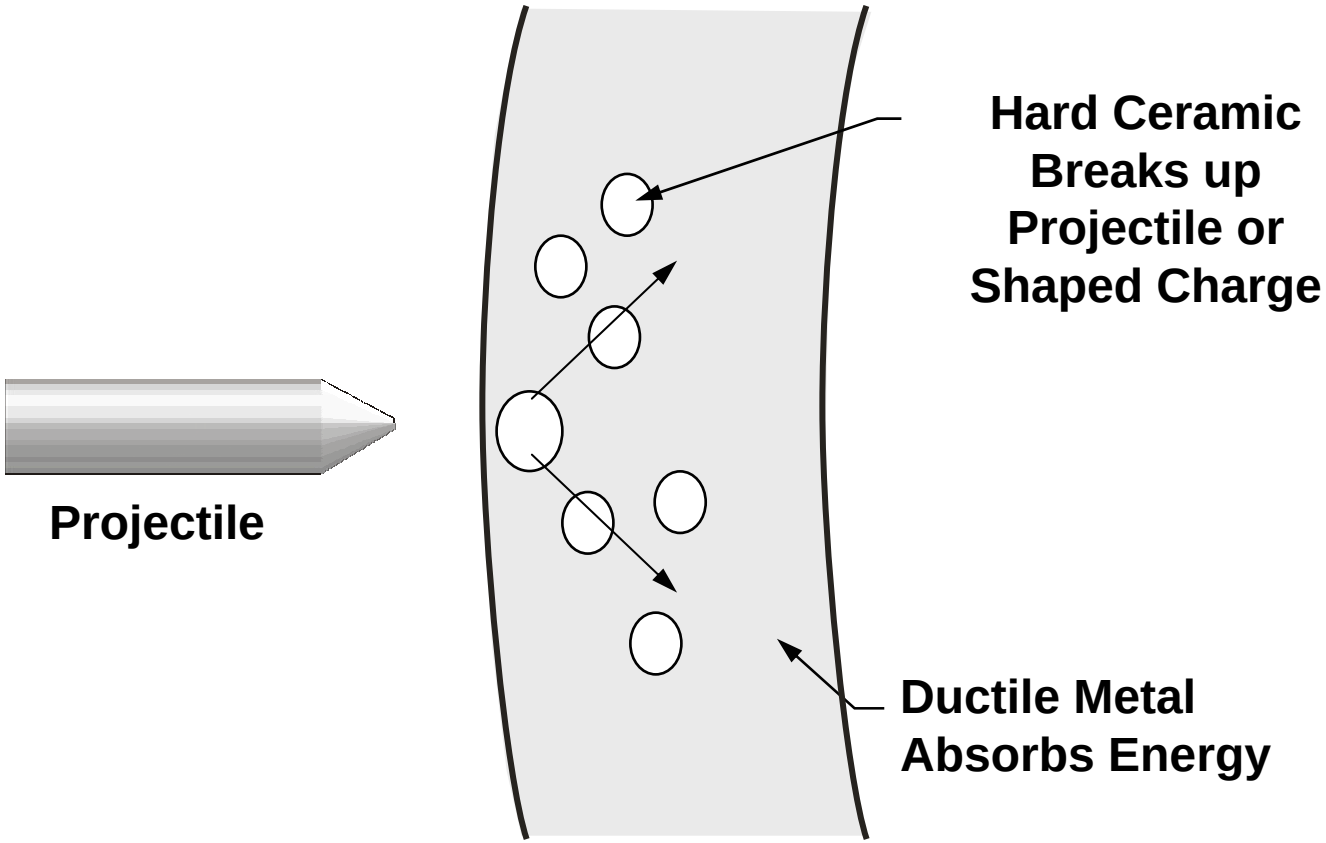
Radiation



Minimum Weight Cask With Variable Density Shield

Cermets Make Superior Armor Against Accidents and Assault

(No Single Material Has All the Desired Properties)



Cermets Are the Preferred Spent Nuclear Fuel Cask Material

(If Economic Methods of Cermet Cask Manufacture Exist)

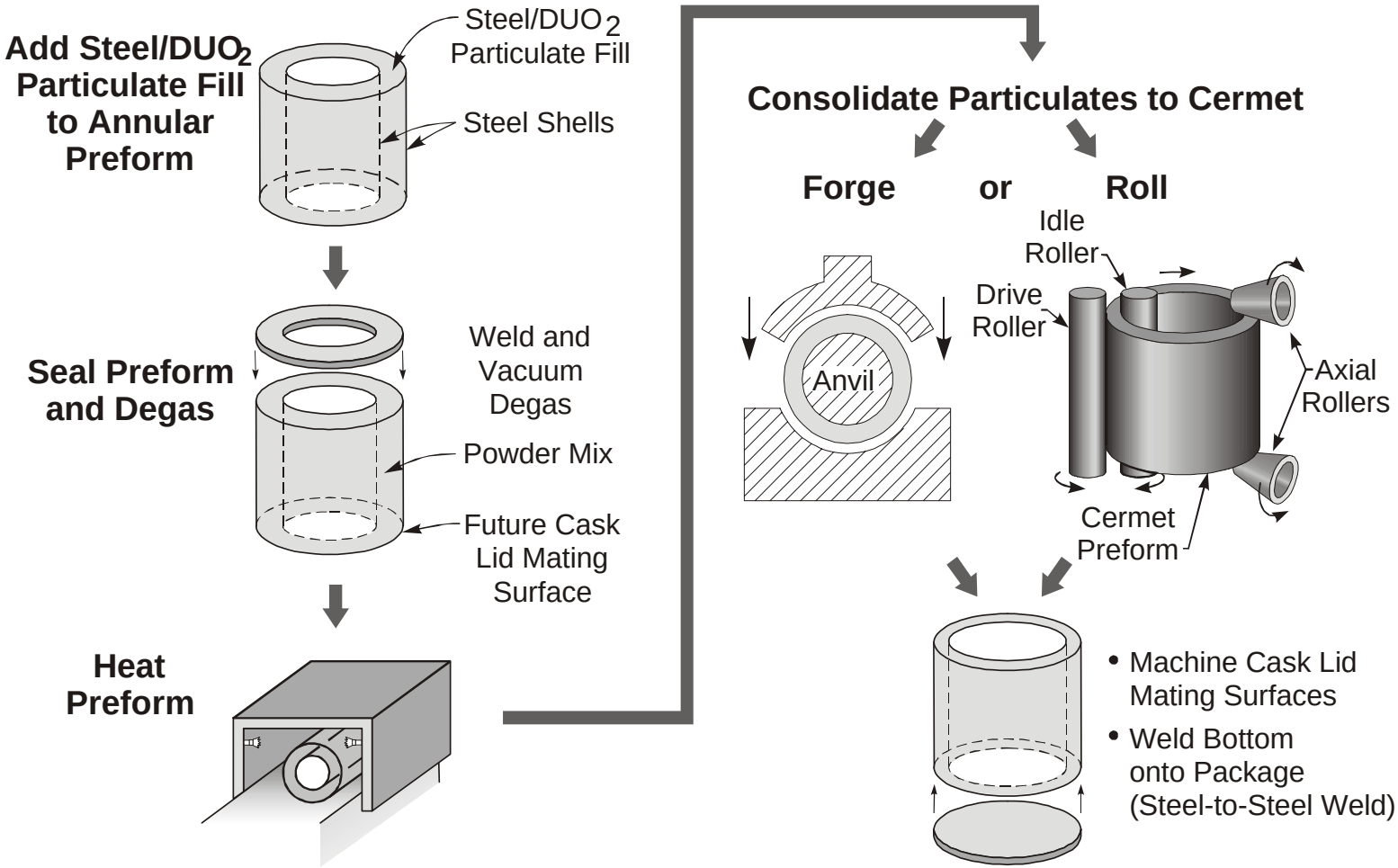
A New Low-Cost Method to Fabricate Cermet Casks Is Being Developed

Manufacturing Requirements to Minimize Cask Cost

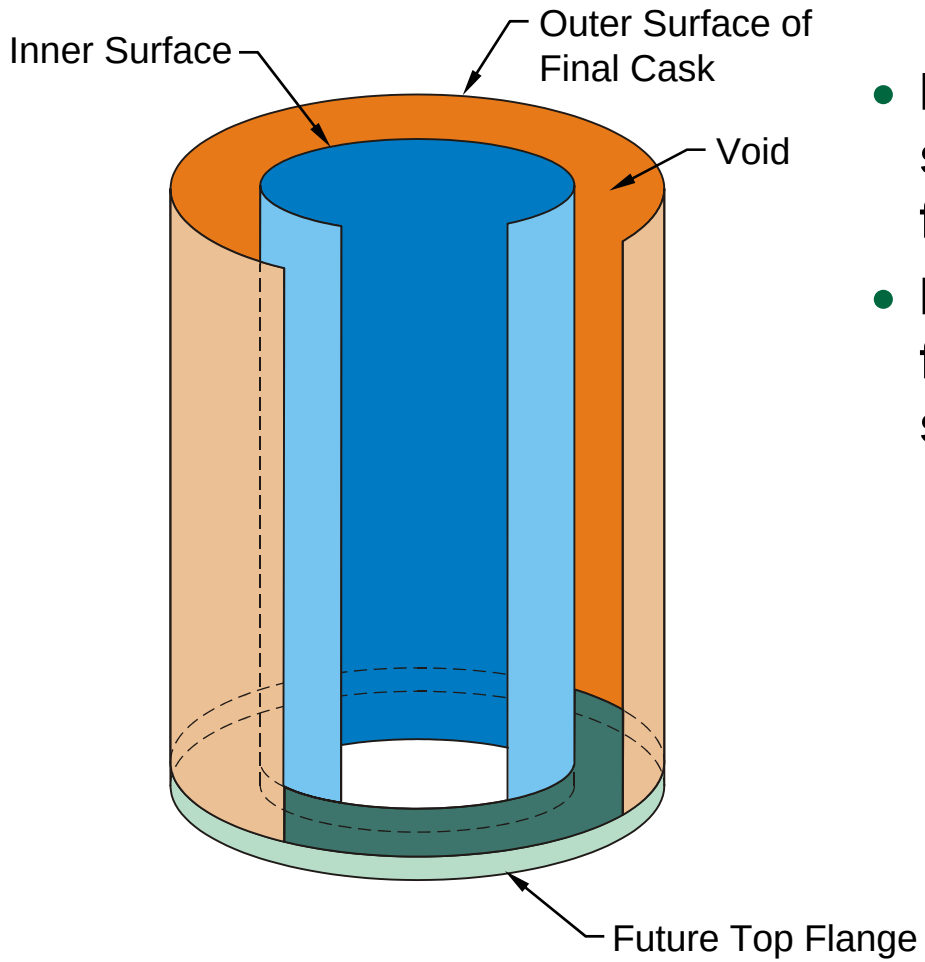
- Minimum number of operations
  - No cermet welding (extremely difficult)
  - Minimum cermet forming (difficult)
- Low-cost raw materials
- Minimum plant-area handling of DUO_2
  - Contamination control requirements
  - Regulatory complications
- Appropriate QA/QC

New Production Method for Cermet Casks

(Patent Application Filed)

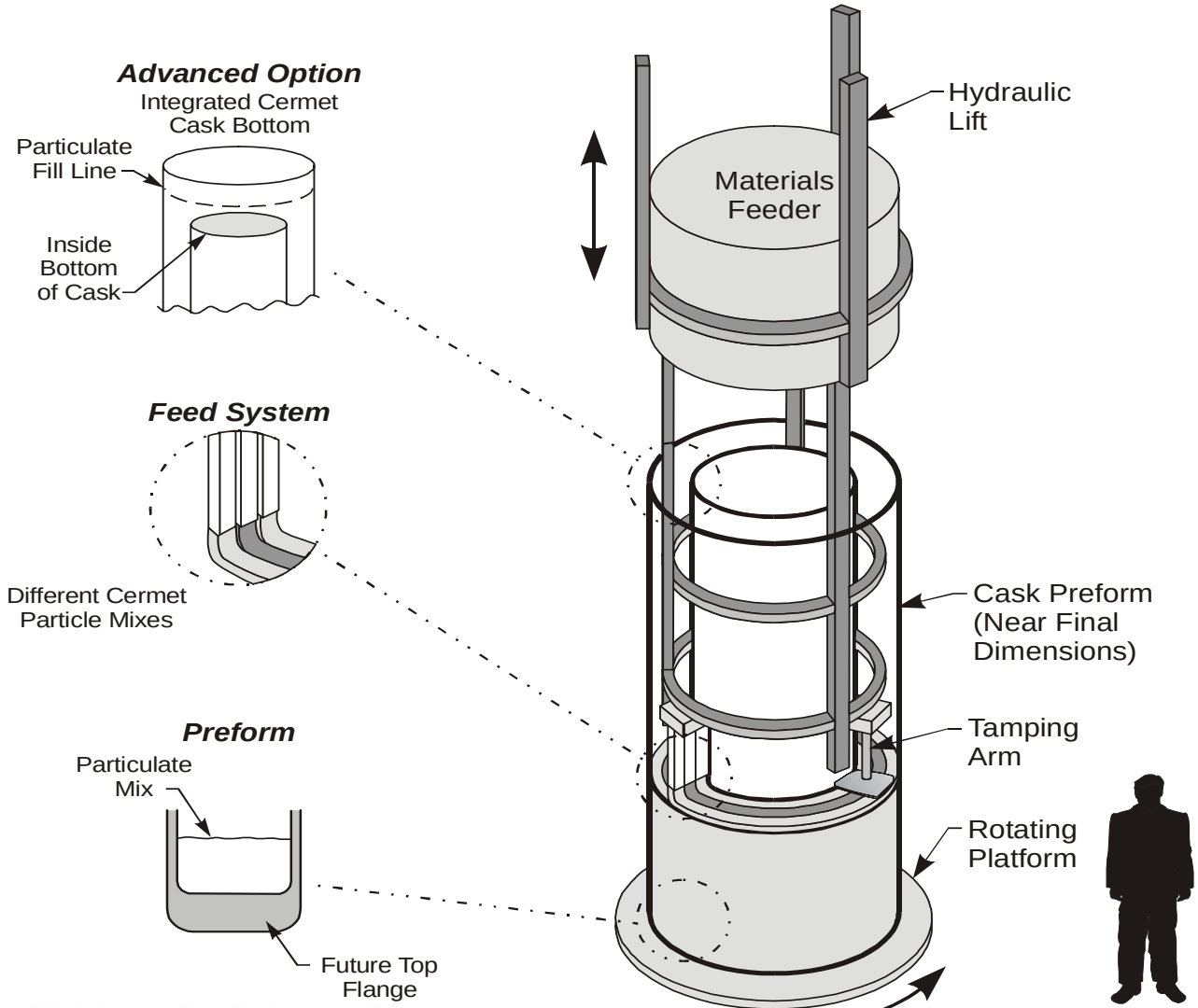


New Fabrication Method (Patent Applied for): Step 1: Manufacture of Cask Preform

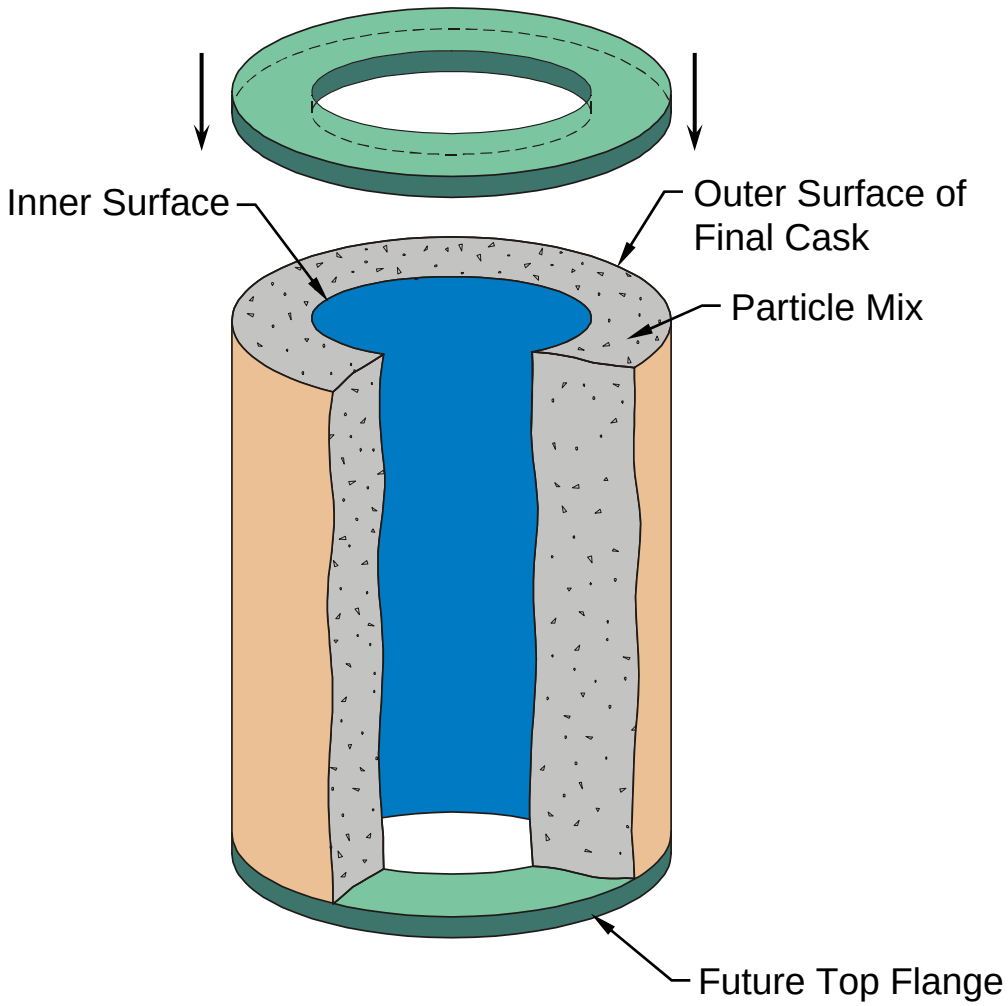


- **Preform dimensions are slightly larger than the final cask**
- **Preform becomes the final inner and outer surfaces of the cask**
  - **Wall thickness: 1-3 cm**
  - **Flange**
    - **Thickness: 10-20 cm**
    - **Face for lid**

Step 2: Empty Cask Preform Is Mounted Upside Down on a Turntable and Filled with Cermet Particulate Mixture



Step 3: Loaded Preform Is Sealed and Degassed

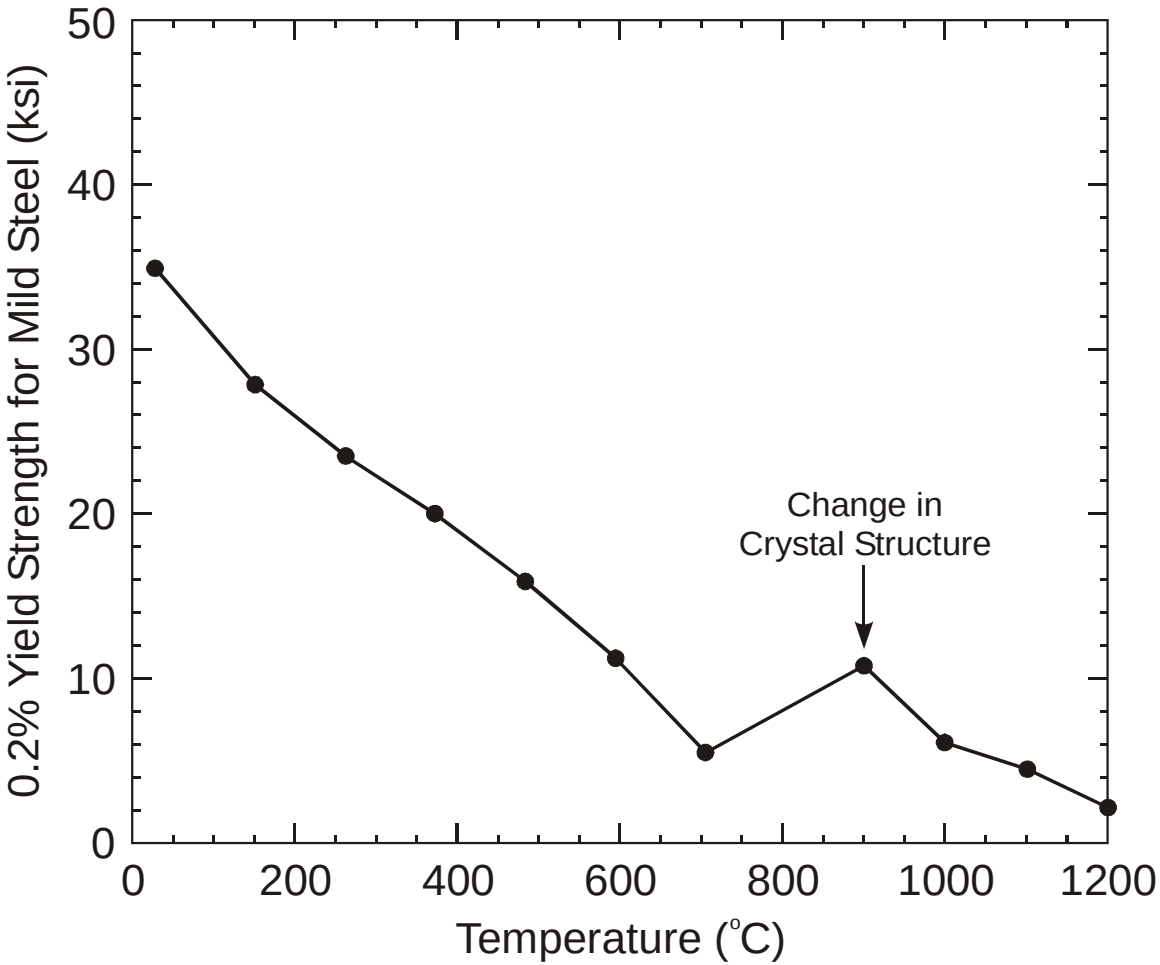


- **Weld annular ring to seal preform**
- **Degas**
  - **Heat**
  - **Vacuum**
- **Send sealed package to forging operations**

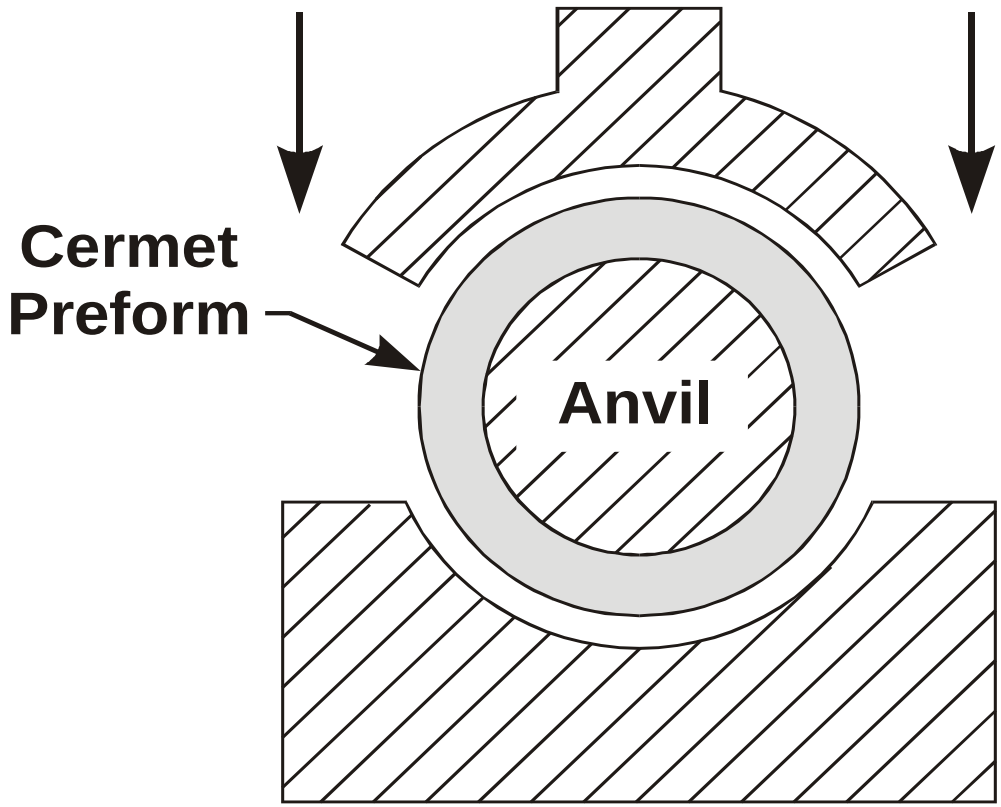
Step 4: Pressure and Temperature Convert the Cermet Particulate Mix into a Monolithic Metal-Lined Cermet Cask

- **Filled preform is heated before cermet particulate consolidation operations**
  - **Heating reduces forces required for later forging operations**
  - **Heating ensures that metal particulates are welded by forging operations**
- **Pressure (forging) creates monolithic cask (no voids) with preform and cermet welded together**

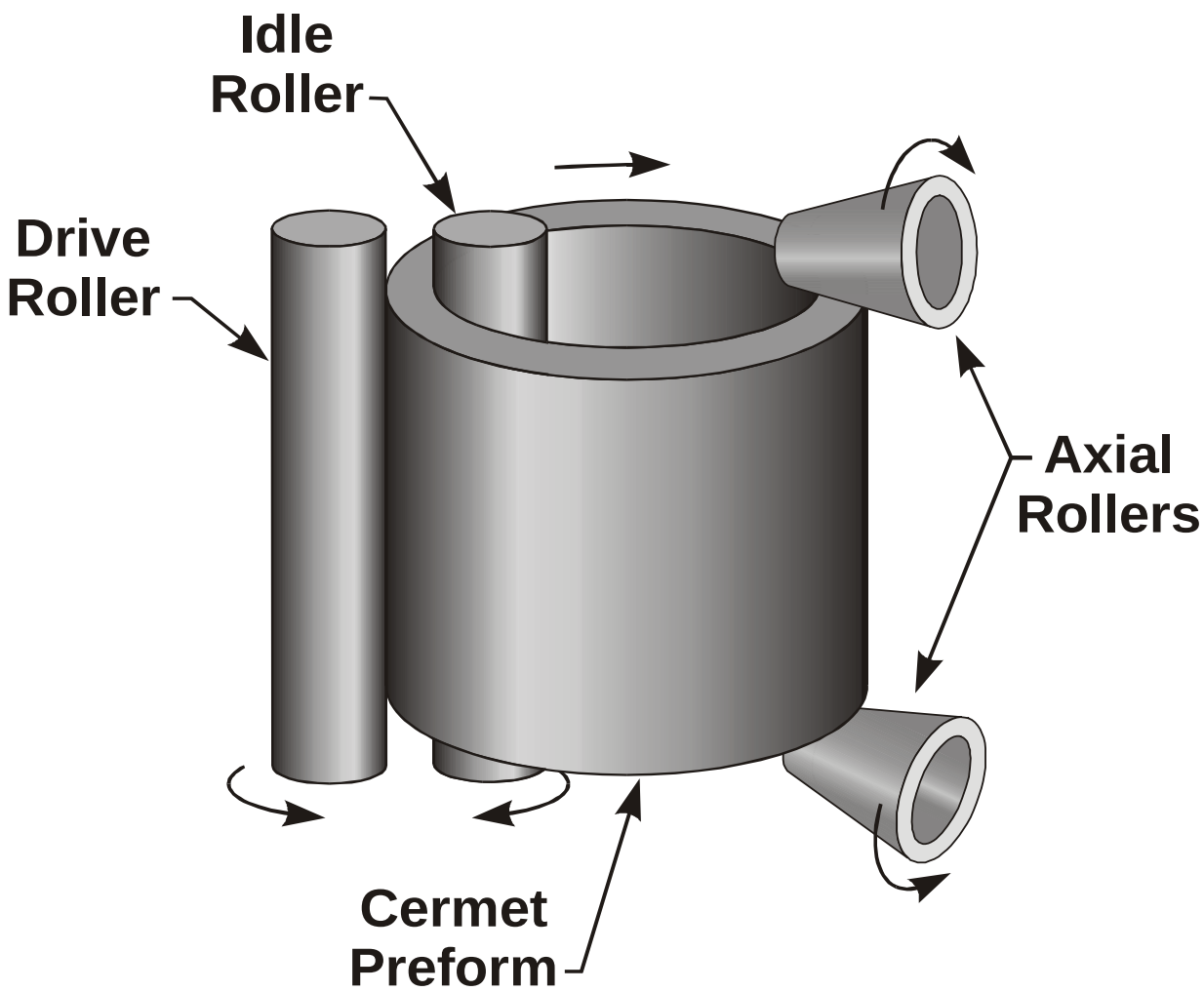
Step 4a: Heating the Loaded Preform Reduces Consolidation Forces for Conversion into a Monolithic Cask



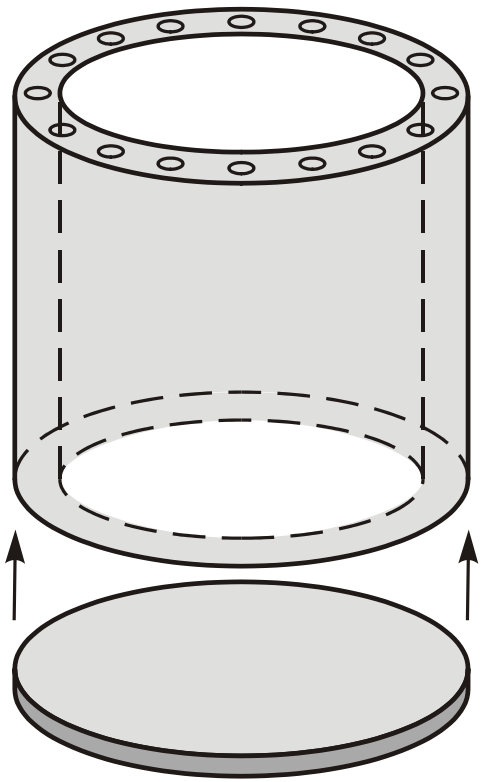
Step 4b: Cermet Consolidation Option Using Open Dye Forging (Standard Industrial Operation)



Step 4b: Cermet Consolidation Option Using Rolled Ring Forging



Step 5: Cask Finishing Operations



- All finishing operations involve steel preform (No contact with cermet)
- Cask bottom is welded to the cask body
  - Option for integrated cask bottom
  - Option requires complex forging operation
- Cask machining
  - Machine lid surface and bolt holes
  - Cask surfaces

The Potential Exists for Low Costs

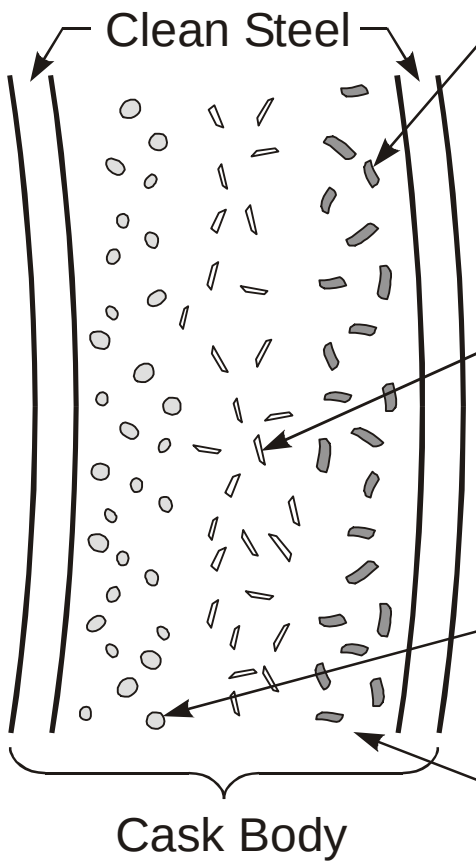
- Raw-materials costs are low
  - DUO_2: zero cost or rebate (avoidance of disposal costs)
  - Other cermets: depends upon choices
  - Iron powder: $600/ton
    - Very large production of powered metals
    - Automotive gears and other parts made by powder metallurgy
- Labor costs are low
- Option to use existing facilities for forging
  - Sealed preform
  - Several options for cermet consolidation

Path Forward

- Detailed manufacturing studies (theory and experimental)
  - Without DUO_2
  - With DUO_2
- Cost studies
  - Without DUO_2(option to first introduce non-DUO_2, then DUO_2 cermet)
  - With DUO_2
- Request cask vendor assistance and input

Backup Slides

The Composition Across the Cermet Can Be Varied to Maximize Cask Performance
(Including Increased Capacity for a Given Weight Limit)



Ceramics for Armor Protection (Traditional Cermet Application)
- DUO_2
- Al_2O_3
- SiC

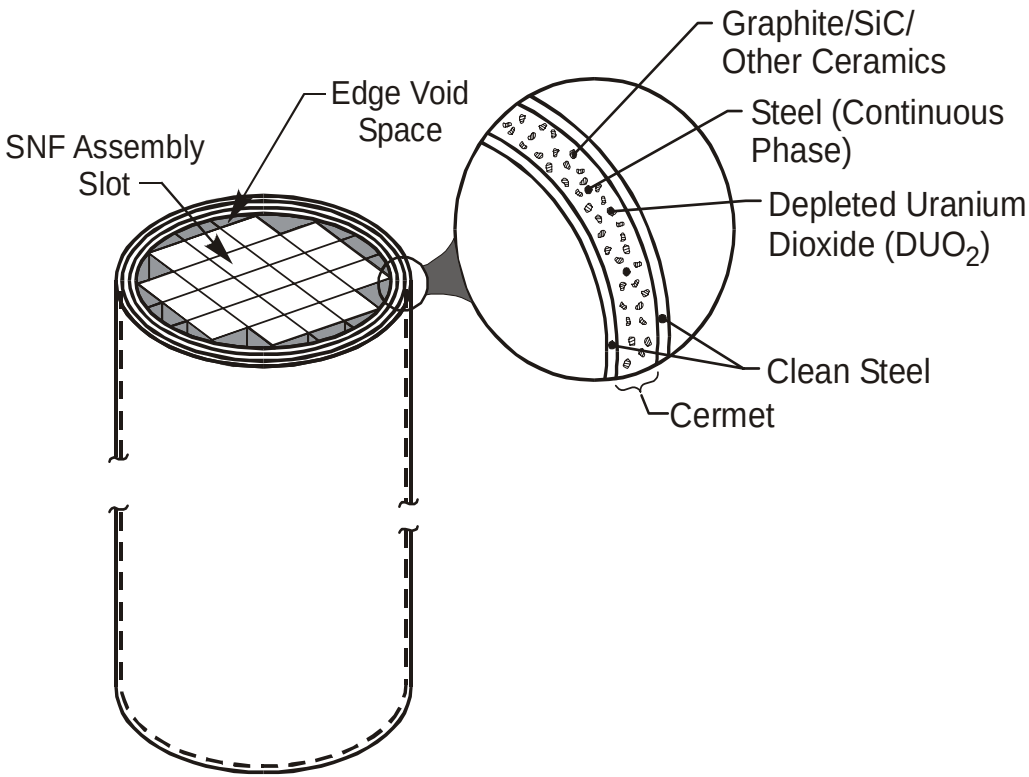
Ceramics for Neutron Moderation or Absorption
- DUO_2
- SiC
- Gd_2O_3

Ceramics for Gamma Shielding
- DUO_2

Metal Matrix
- Strength
- Thermal Conductivity

Cermets Are the Enabling Technology for a High-Performance Super Cask

(Ceramics in Metal Matrix to Obtain Advantages of Both)



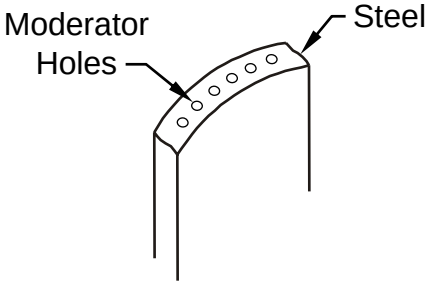
Functions

- 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

Cermet Casks May Require Fewer Fabrication Steps than Traditional Casks

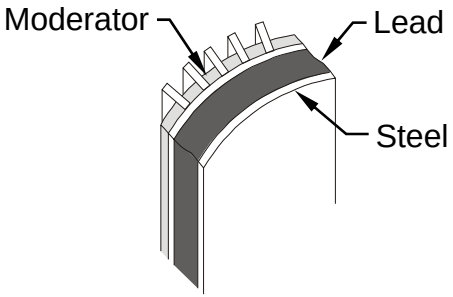
Other Casks

Steel Cask



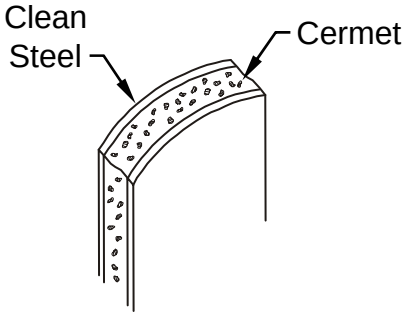
- **Casting**
- **Drilling**
- **Assembly**
- **Machining**

Lead Cask



- **Form Fabrication**
- **Casting**
- **Moderator Placement**

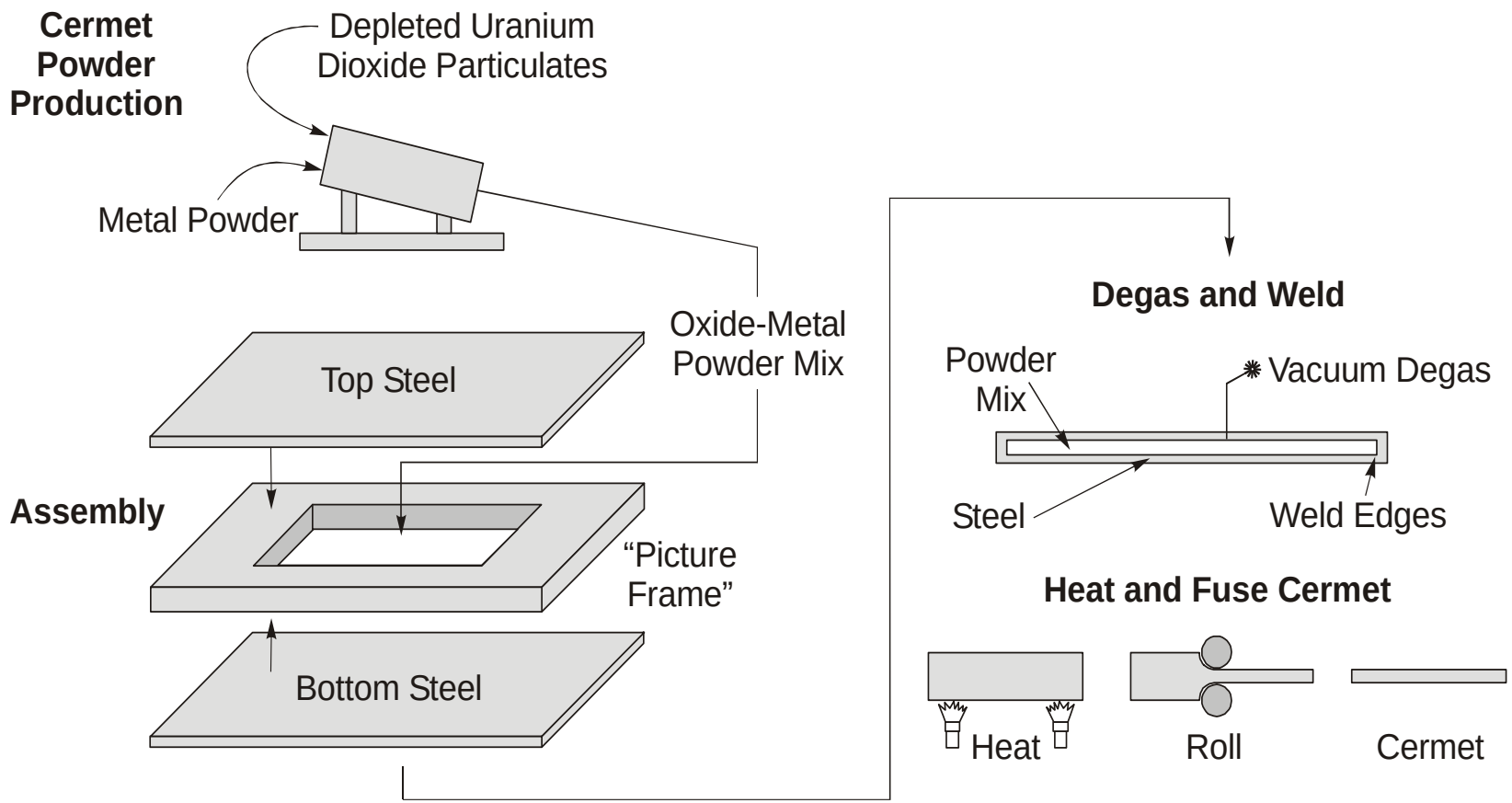
Cermet



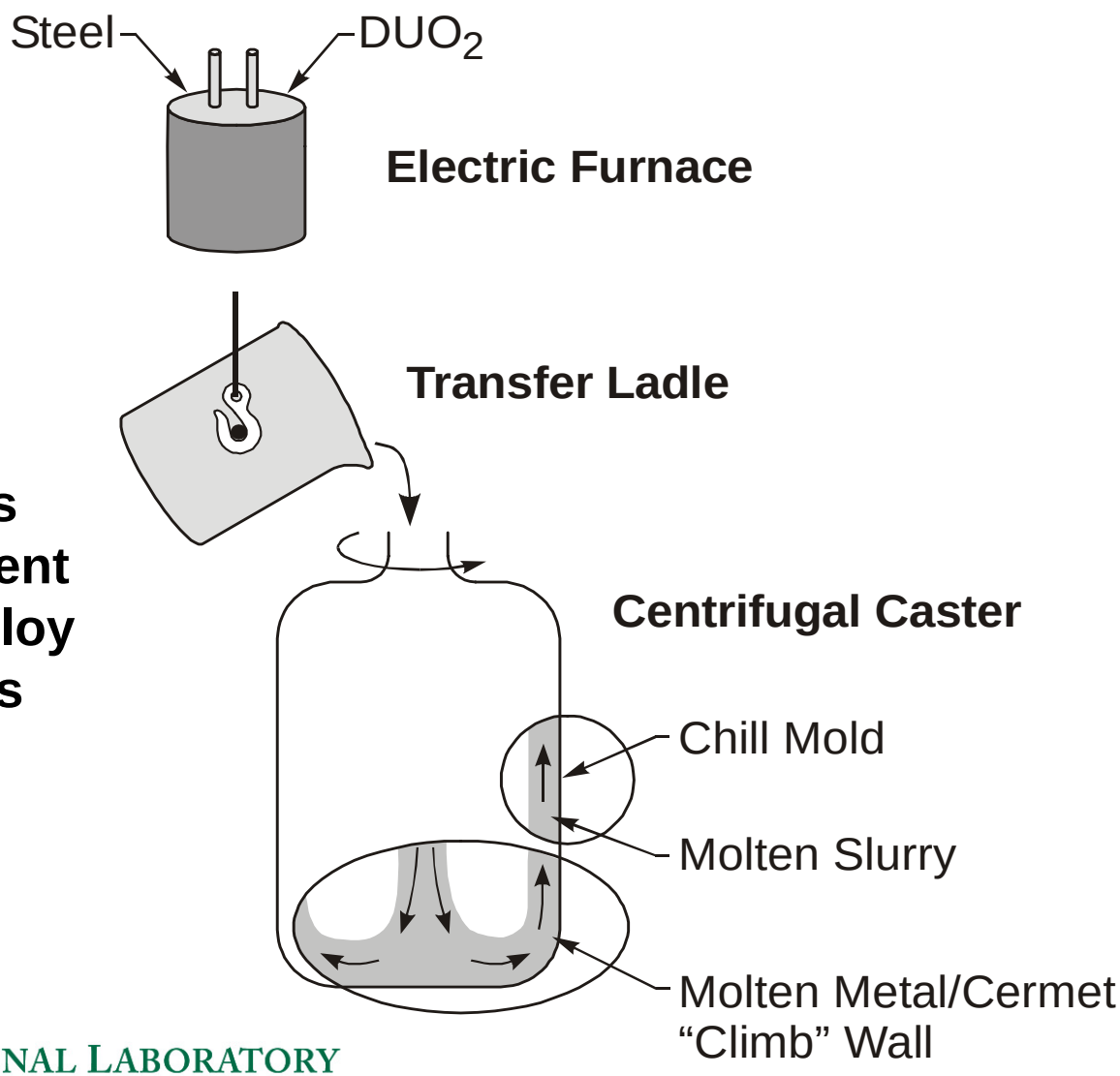
- **Form Fabrication**
- **Particulate Addition**
- **Heat and Forge**

Traditional "Picture-Frame" Method for Cermet Production

(Requires Assembly of Cask from Cermet Pieces; Welding Cermets Is Extremely Difficult)



Cask Production by DUO_2 Particulate / Molten-Steel Centrifugal Casting



Requires Development of Metal Alloy that Wets DUO_2