Cask Size and Weight Reductions Through the Use of DUCRETE

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Outline

• Background of U.S. and DUCRETE Program

• Update laboratory DUAGG exposure testing

• Update preconceptual design and costing of DUCRETE cask fabrication
Consumption in Storage/Transport Casks for projected Commercial SNF

Potential Use of UO$_2$ in SNF Storage for 24 PWR and 61 BWR Assemblies per Storage Silo

- **BWR**
- **PWR**
- **Total tonnes**


UO$_2$, tonne

- 0
- 100,000
- 200,000
- 300,000
- 400,000
- 500,000
Yearly Rate of Spent Fuel Assemblies (no inventory included)
Yearly Rate of Spent Fuel Storage/Transport Casks (no inventory included)
Hypothetical Number of Casks for the Accumulated PWR and BWR Assemblies (including inventory)
Design Capacity of the Plant

- Plant produces 50 storage/transport casks per year, operating in one 8-hr shift
- Operates for 25 years
- Casks will store the equivalent to about 25% the inventory of PWR inventory or could store the equivalent to about 45% of BWR inventory
DUCRETE Casks are Considerably Smaller and Lighter than Casks Constructed of Ordinary Concrete

The DUCRETE cask is 35 tons lighter and 100 cm smaller in diameter than casks made from ordinary concrete.

Comparison of conventional and DUCRETE spent-fuel dry storage casks/silos
Substitute DUCRETE in GNB CONSTOR Cask and Optimize Design

- Reduce size and weight
- Allow higher thermal loads
- Meet technical and economic performance criteria
- Comply with regulatory requirements and standards
Russian RBMK Spent Fuel Cask with Heavy Concrete

GNB CONSTOR test cask for RBMK SNF

Heavy concrete with steel shot and barium sulfate
RMBK SNF Shipments in Russia

A train carrying a load of spent nuclear fuel from a Ukrainian nuclear power plant arrived at Zheleznogorsk, Krasnoyarsk County

DUAGG Briquettes are Stabilized DU Aggregates with Basalt Sintering Agent

Briquettes are pressed, solidified by liquid-phase sintering, crushed, and gap-graded for use in high-strength DUCRETE at 5000 to 6000 psi, (35–42 MPa)
## Composition of DUAGG

<table>
<thead>
<tr>
<th>Element</th>
<th>wt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>0.61</td>
</tr>
<tr>
<td>Copper</td>
<td>0.04</td>
</tr>
<tr>
<td>Iron</td>
<td>0.42</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.14</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.15</td>
</tr>
<tr>
<td>Silicon</td>
<td>2.16</td>
</tr>
<tr>
<td>Strontium</td>
<td>0.01</td>
</tr>
<tr>
<td>Titanium</td>
<td>1.35</td>
</tr>
<tr>
<td>Uranium</td>
<td>93.71</td>
</tr>
<tr>
<td>Zirconium</td>
<td>0.85</td>
</tr>
</tbody>
</table>
Current DUAGG Exposure Studies
Using ASTM C289-94 Standard Test Method

At a consistent surface-to-liquid ratio of 1:10, the sintered DUAGG samples are exposed to:

(1) distilled water
(2) 1N sodium hydroxide standard solution
(3) saturated water extract of high-alkali cement

The three exposure temperatures and six times are as follows: 25, 66, and 150ºC at intervals of 30, 60, 90, 180, 360, and 730 days
View of DUAGG Before Testing

Detail of the surface (secondary electrons)

Particle A contains Al

Particle B contains Ti and some Mg

Area C contains DUO₂ particles surrounded by dark basalt
DUAGG After 6 Months in DI Water

150°C — secondary electrons

Particles A contain Ti and some Mg
DUAGG After 6 Months in Cement Pore Solution

Covered by CaCO₃ and needle-like crystals containing Ca, Si, and some Al
Silicates form a dense diffusion layer on the surface of UO2 even under oxidizing conditions.
High-silica forces formation of insoluble uranium silicates
## Principal U(VI) Compounds

Values of $\Delta G_{f,298}^\circ$ for the U(VI) minerals used in the construction of Fig. 7 (Chen 1999)

<table>
<thead>
<tr>
<th>Uranyl phases</th>
<th>Formula</th>
<th>kJoule/mol$^a$</th>
<th>kJoule/mol$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metaschoepite</td>
<td>$[(\text{UO}<em>2)</em>{5}\text{O}<em>2\text{(OH)}</em>{12}]^+(\text{H}<em>2\text{O})</em>{10}$</td>
<td>$-13,092.0$</td>
<td>$-13,092.0$</td>
</tr>
<tr>
<td>Becquerelite</td>
<td>Ca$[(\text{UO}<em>2)</em>{5}\text{O}<em>4(\text{OH})</em>{6}]^+(\text{H}<em>2\text{O})</em>{8}$</td>
<td>$-10,324.7$</td>
<td>$-10,305.8$</td>
</tr>
<tr>
<td>Rutherfordine</td>
<td>$\text{UO}_2\text{CO}_3$</td>
<td>$-1,563.0$</td>
<td>$-1,563.0$</td>
</tr>
<tr>
<td>Urancalcarite</td>
<td>Ca$_2[(\text{UO}<em>2)</em>{3}\text{(CO}_3\text{)(OH)}_6]^+(\text{H}<em>2\text{O})</em>{3}$</td>
<td>$-6,036.7$</td>
<td>$-6,037.0$</td>
</tr>
<tr>
<td>Sharpite</td>
<td>Ca$[(\text{UO}<em>2)</em>{6}\text{(CO}_3\text{)}_3\text{(OH)}_4]^+(\text{H}<em>2\text{O})</em>{6}$</td>
<td>$-11,607.6$</td>
<td>$-11,601.1$</td>
</tr>
<tr>
<td>Fontaninite</td>
<td>Ca$[(\text{UO}<em>2)</em>{3}\text{(CO}_3\text{)}_4]^+(\text{H}<em>2\text{O})</em>{3}$</td>
<td>$-6,524.7$</td>
<td>$-6,523.1$</td>
</tr>
<tr>
<td>Liebigite</td>
<td>Ca$_2[(\text{UO}<em>2)</em>{2}\text{(CO}_3\text{)}_3]^+(\text{H}<em>2\text{O})</em>{11}$</td>
<td>$-6,446.4$</td>
<td>$-6,468.6$</td>
</tr>
<tr>
<td>Haiweeite</td>
<td>Ca$[(\text{UO}<em>2)</em>{2}\text{(Si}_2\text{O}_5\text{)}_3]^+(\text{H}<em>2\text{O})</em>{5}$</td>
<td>$-9,367.2$</td>
<td>$-9,431.4$</td>
</tr>
<tr>
<td>Ursilite</td>
<td>Ca$_4[(\text{UO}<em>2)</em>{4}\text{(Si}_2\text{O}_5\text{)(OH)}_6]^+(\text{H}<em>2\text{O})</em>{15}$</td>
<td>$-20,377.4$</td>
<td>$-20,504.6$</td>
</tr>
<tr>
<td>Soddyite</td>
<td>$[(\text{UO}<em>2)</em>{2}\text{Si}_4\text{O}_4]^+(\text{H}<em>2\text{O})</em>{2}$</td>
<td>$-3,653.0$</td>
<td>$-3,658.0$</td>
</tr>
<tr>
<td>Uranophane</td>
<td>Ca$[(\text{UO}<em>2)</em>{2}\text{(Si}_3\text{O}_5\text{OH)}_2]^+(\text{H}<em>2\text{O})</em>{5}$</td>
<td>$-6,192.3$</td>
<td>$-6,210.6$</td>
</tr>
</tbody>
</table>

$^a$ Chen 1999  $^b$ Finch 1997
Conclusions on DUAGG Testing

- After >24 months of exposure, the release rate of uranium in a cement pore solution is low and shows that DUAGG is superior to pure UO$_2$.
- A protective layer of recrystallization products from the basalt phase of DUAGG cover the surface, slowing the release of uranium.
- In the cement pore solution, after >24 months of exposure, no deleterious products from the alkali-aggregate reaction were seen.
Conclusions on DUAGG Testing (continued)

• Results show that DUAGG can be expected to be stable under the casks’ service conditions.

• We are continuing laboratory experiments to characterize DUAGG/DUCRETE materials and their behavior in SNF cask applications.

• We are pursuing a collaboration with the Russians to design and demonstrate the next generation of SNF transport and storage casks.
Conclusions of DUAGG Price Study

- Labor is primary cost
  - Reduce by privatization
  - Reduce by integrating with DUF6 conversion
  - Reduce labor intensive processing steps

- Cost of Producing DUAGG, $138,000 per cask (62 tons DUAGG per cask)
Preconception Cask Design and Fabrication Cost Study

CONSTOR Cask Fabrication used as Baseline
Process Sequence

- Inner Cylinder
  - Inner Cylinder Cleaning
  - Inner Cylinder Surface Preparation
  - Reinforcement Bars in Inner Cyl.
  - Sliding Outer Cyl Into Inner Cyl.
  - Upside Down
  - Filling cask with DUO2 and cement
  - Welding Bottom Cover to Cask
  - Upside position Cover and store

- Outer Cylinder
  - Welding Head To Inner Cyl.
  - Outer Cylinder Surface Preparation
  - Welding Head To Inner Cyl.
  - Filling cask with DUO2 and cement
  - Welding Bottom Cover to Cask
  - Upside position Cover and store

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY
Some Fabrication Steps
Assumptions

• Plant can manufacture 50 casks per year working one shift per day

• The manufacturing plant receives DUAGG, cement, and steel pre-fabricated parts to make the casks

• It takes three days (1 shift) to make a cask

• The plant will work 5 days a week
Surface Area Required

- General Storage Area
- Cask Manufacturing Area
- Administration
- Utilities
- Waste Management

Dimensions:
- 100’
- 200’
- 400’
- 50’
Capital Cost Components

- Civil/site preparation
- Utilities building services
- Process equipment
- Land and buildings
- Special process services
- Engineering
- Piping
- Electrical
- Spare parts
- Management
- Shipping
- Safety system
- Installation labor
Capital Cost

- Capital cost has been estimated for a plant capable of manufacturing 50 casks per year (in one 8-hr shift)

- The estimated capital cost for this plant is $17.1M
Operation Cost Calculation

- Labor
- Cement
- DUAGG
- Utilities
- Waste Management
- Administration

- Inner cylinders
- Outer cylinders
- Bottom covers
- Cask primary lid
- Cask secondary lid
- Paint
Labor Cost for the Baseline Case of 50 Casks Per Year

- **Operators**
  
  Labor cost for operators : $70/hr
  
  For production of 50 casks : $70/hr * 2080 hr/yr * 13 = $1,900K/yr

- **Administration**
  
  Secretary : $30/hr * 2080 hr/yr = $62.4K/yr
  
  Shift superintendent : $80/hr * 2080 hr/yr = $166.4K/yr
  
  General Manager : $90/hr * 2080 hr/yr = $187.2K/yr

**Total Annual Labor Cost:** $2,316K/yr
Production Cost per Storage/Transport Cask

Analysis was made for three cases: 50, 100, and 150 casks per year

Assumes:
Capital Recovery Factor: 25%
US Questions

• What would such a business analysis look like for Russian manufacturing facilities in the context of Russian and international market analyses?

• What, if any, are Russia’s long-range plans for the implementation of these technologies?
Extra Slides

Support Discussions and Questions
U released from DUAGG into Cement and Blast-furnace Slag Porewater

Uranium released (%) from DUAGG pellet

Time, months

% released

0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
-0.0001

0 5 10 15 20 25 30

OPC-20C
BFS-20C
OPC-67C
BFS-67C
OPC-150C
BFS-150C
U Released from High-fired UO₂ Fuel Pellet into Cement and Slag Porewater

Uranium released (%) from DUO2 pellet

% released

-0.0005
0
0.0005
0.001
0.0015
0.002
0.0025
0.003
0.0035
0.004

0  1  2  3  4  5  6  7  8  9  10

Time, months

OPC-20C
BFS-20C
OPC-67C
BFS-67C
OPC-150C
BFS-150C
U Released from High-fired UO2 Fuel Pellet into 1 N NaOH and Distilled Water

Uranium released (%) from DUO2 pellet

- NAOH-20C
- DW-67C
- NAOH-67C
- DW-150C
- NAOH-150C
- DW-20C
Si Released from DUAGG into 1N NaOH and Distilled water

Silicon released (%) from DUAGG pellet

Time, months

% released

DIW-20C
NaOH-20C
DM-67C
NaOH-67C
DIW-150C
NaOH-150C
Iron Release

Iron released (%) from DUAGG pellet

% released

Time, months

DIW-20C
NaOH-20C
OPC-20C
BFS-20C
DIW-67C
NaOH-67C
OPC-67C
BFS-67C
DIW-150C
NaOH-150C
OPC-150C
BFS-150C
Titanium Release

Titanium released (%) from DUAGG pellet

% released

Time, months

DIW-20C
NaOH-20C
OPC-20C
BFS-20C
DIW-67C
NaOH-67C
OPC-67C
BFS-67C
DIW-150C
NaOH-150C
OPC-150C
BFS-150C
U released from DUAGG into 1N NaOH and Distilled Water

Uranium released (%) from DUAGG pellet

DIW-20C
NaOH-20C
DIW-67C
NaOH-67C
DIW-150C
NaOH-150C

Time, months

% released

0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45

0 5 10 15 20 25 30
Si released from DUAGG into Cement and Blast-furnace Slag Porewater

Silicon released (%) from DUAGG pellet

Time, months

% released

OPC-20C
BFS-20C
OPC-67C
BFS-67C
OPC-150C
BFS-150C
High-fired DUO\textsubscript{2} Fuel Pellet in 60% OPC + 40% BFS porewater at 67°C for 9 months

Fracture of the cylinder - CaCO\textsubscript{3} visible on the outside surface
High-fired DUO$_2$ Fuel Pellets in 1\textit{N} NaOH solution at 150\textdegree C for 9 months

Side of the exposed fuel-pellet shows grains of DUO$_2$ that are not cohesive
High-fired DUO₂ Fuel Pellets in 1N NaOH solution at 67°C for 9 months

Fracture

Side
High-fired DUO$_2$ Fuel Pellet in 60% OPC + 40% BFS porewater at 20°C for 9 months

Side view with CaCO$_3$ deposits
High-fired DUO$_2$ Fuel Pellet in 60% OPC + 40% BFS porewater at 150°C for 9 months