Cask Size and Weight Reductions Through the Use of DUCRETE

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Russian–American Workshop on Use of Depleted Uranium and Review of International Science and Technology Center (ISTC) Projects
June 19–23, 2005
Moscow and Sarov, Russia

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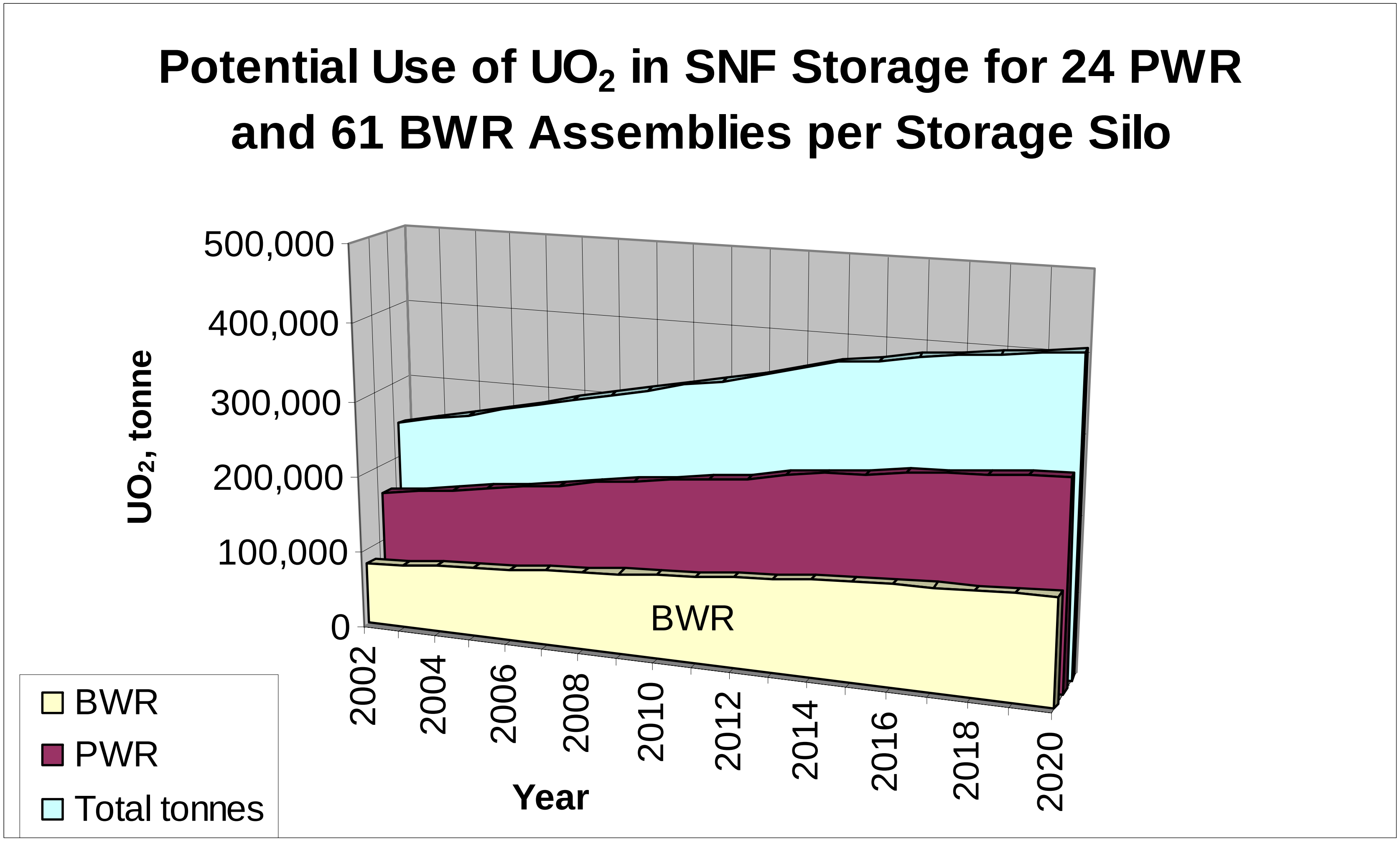
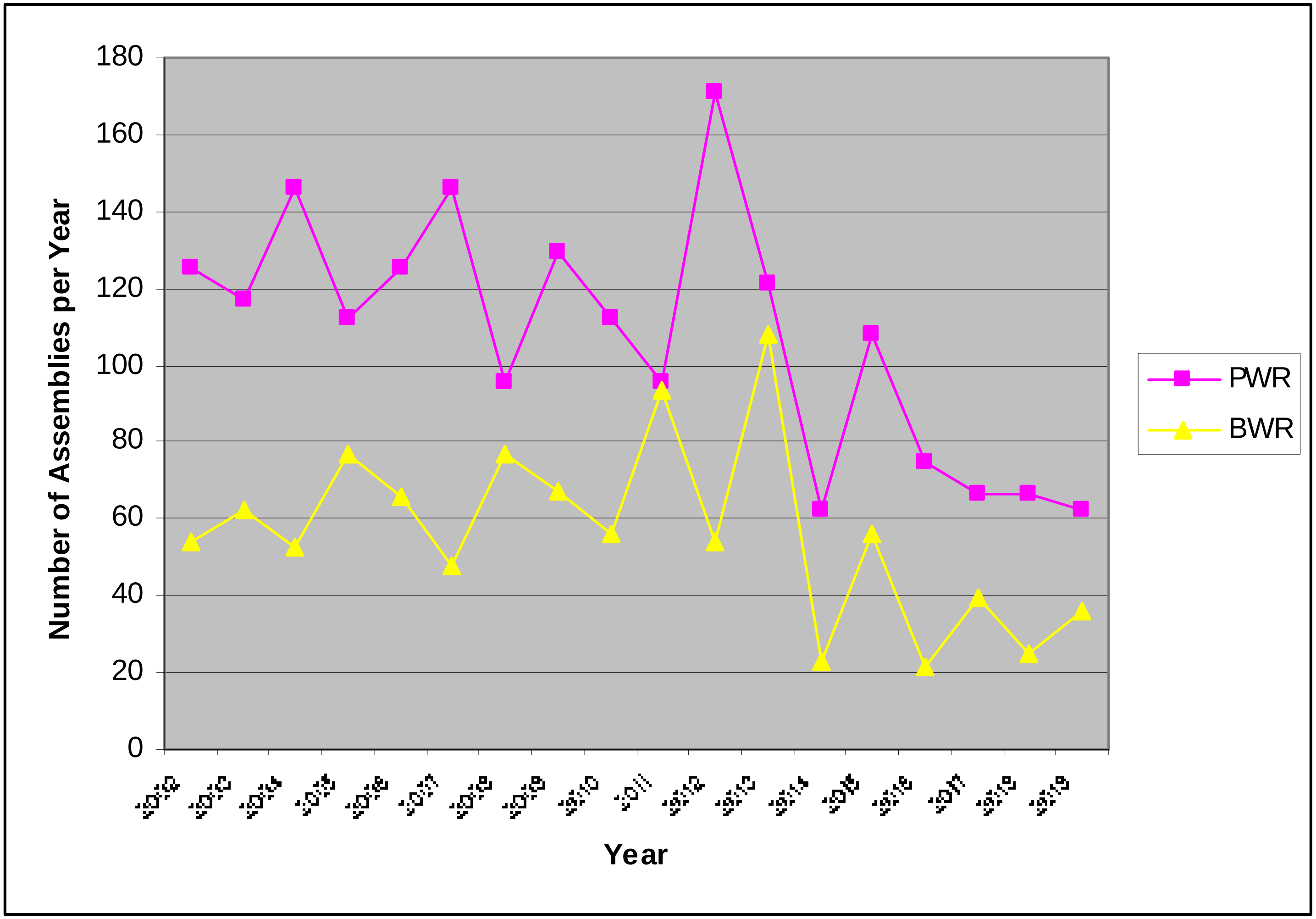
Outline

- **Background of U.S. and DUCRETE Program**
- **Update laboratory DUAGG exposure testing**
- **Update preconceptual design and costing of DUCRETE cask fabrication**

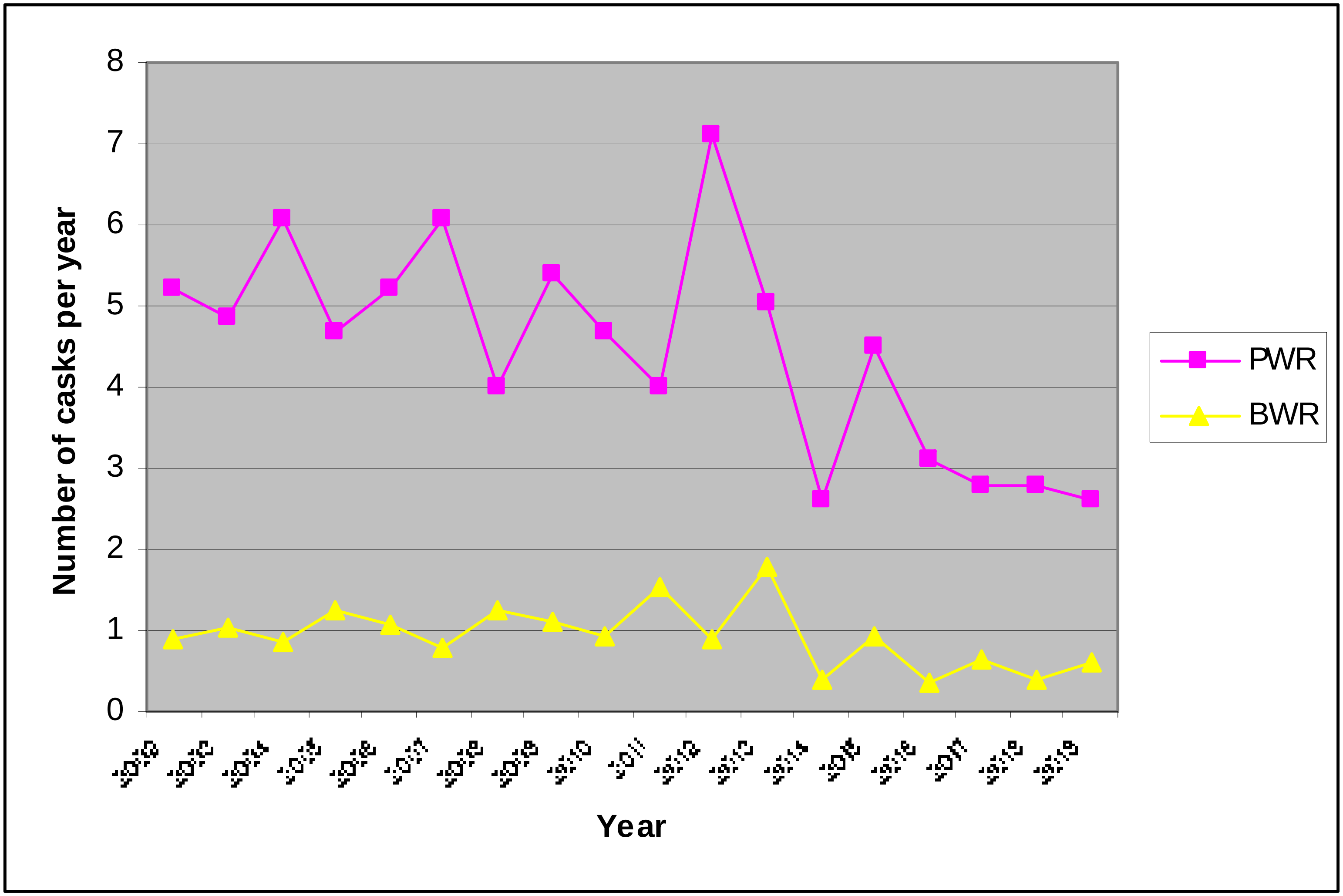
Consumption in Storage/Transport Casks for projected Commercial SNF



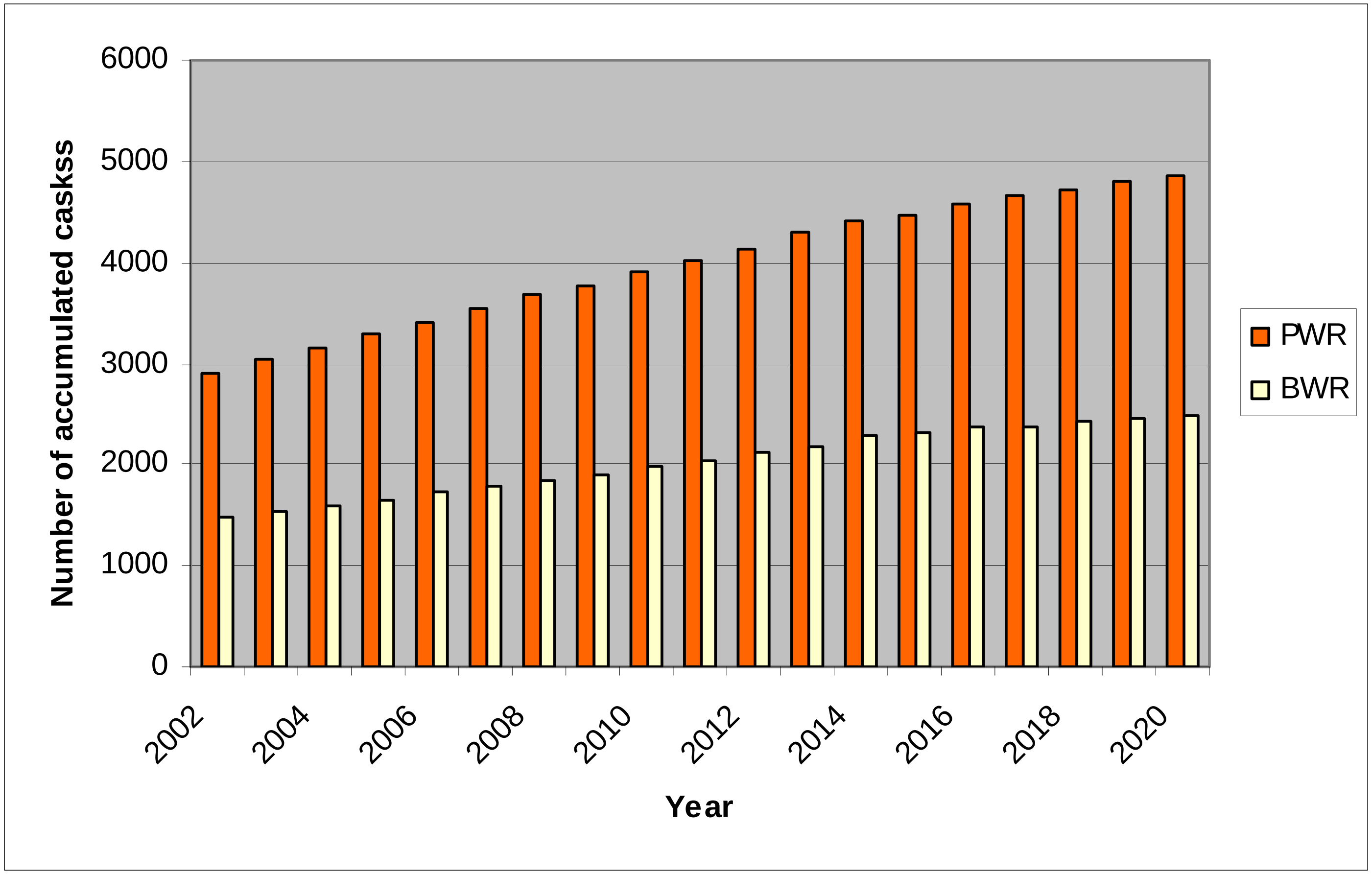
Yearly Rate of Spent Fuel Assemblies (no inventory included)



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

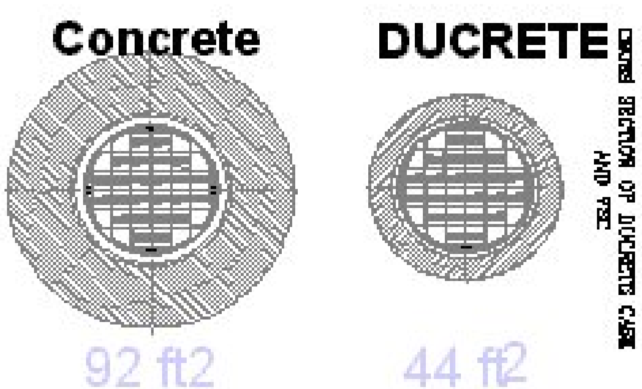
- **Plant produces 50 storage/transport casks per year, operating in one 8-hr shift**

- **Operates for 25 years**

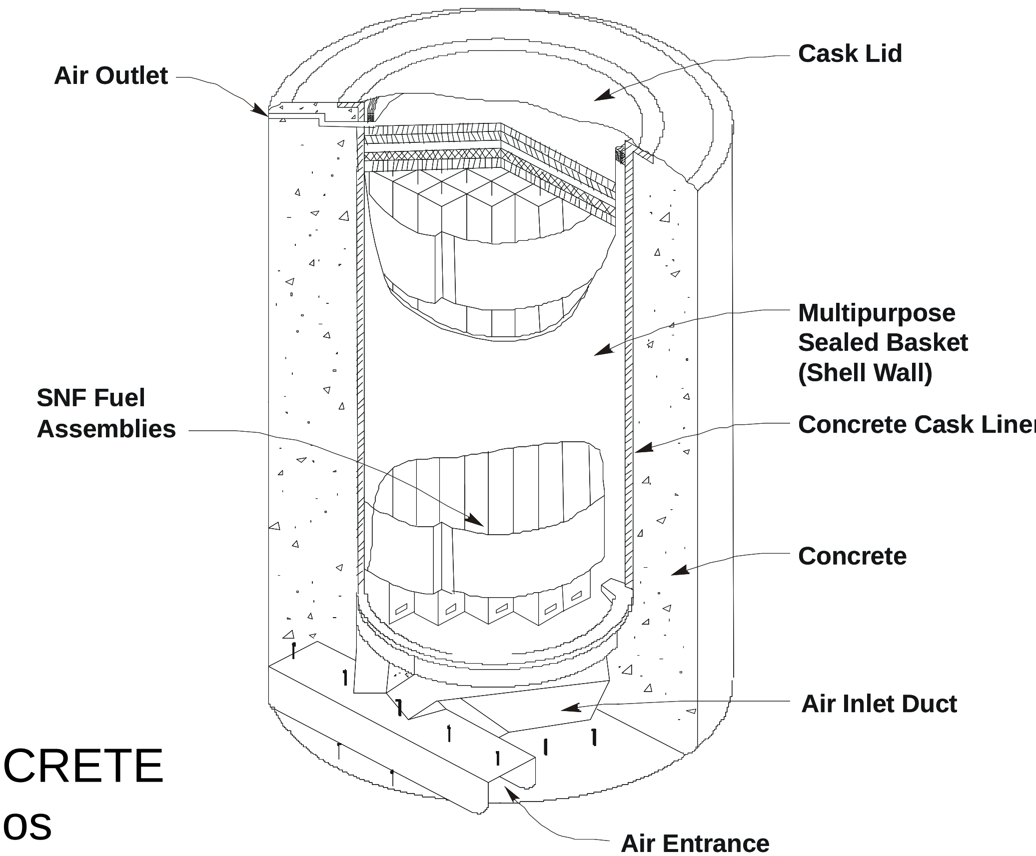
- **Casks will store the equivalent to about 25% the inventory of PWR inventory or could store the equivalent to about 45% of BWR inventory**

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

http://www.bellona.no/en/international/russia/nuke_industry/siberia/zheleznogorsk/16331.html

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

Element	wt %
Aluminum	0.61
Copper	0.04
Iron	0.42
Potassium	0.14
Magnesium	0.15
Silicon	2.16
Strontium	0.01
Titanium	1.35
Uranium	93.71
Zirconium	0.85

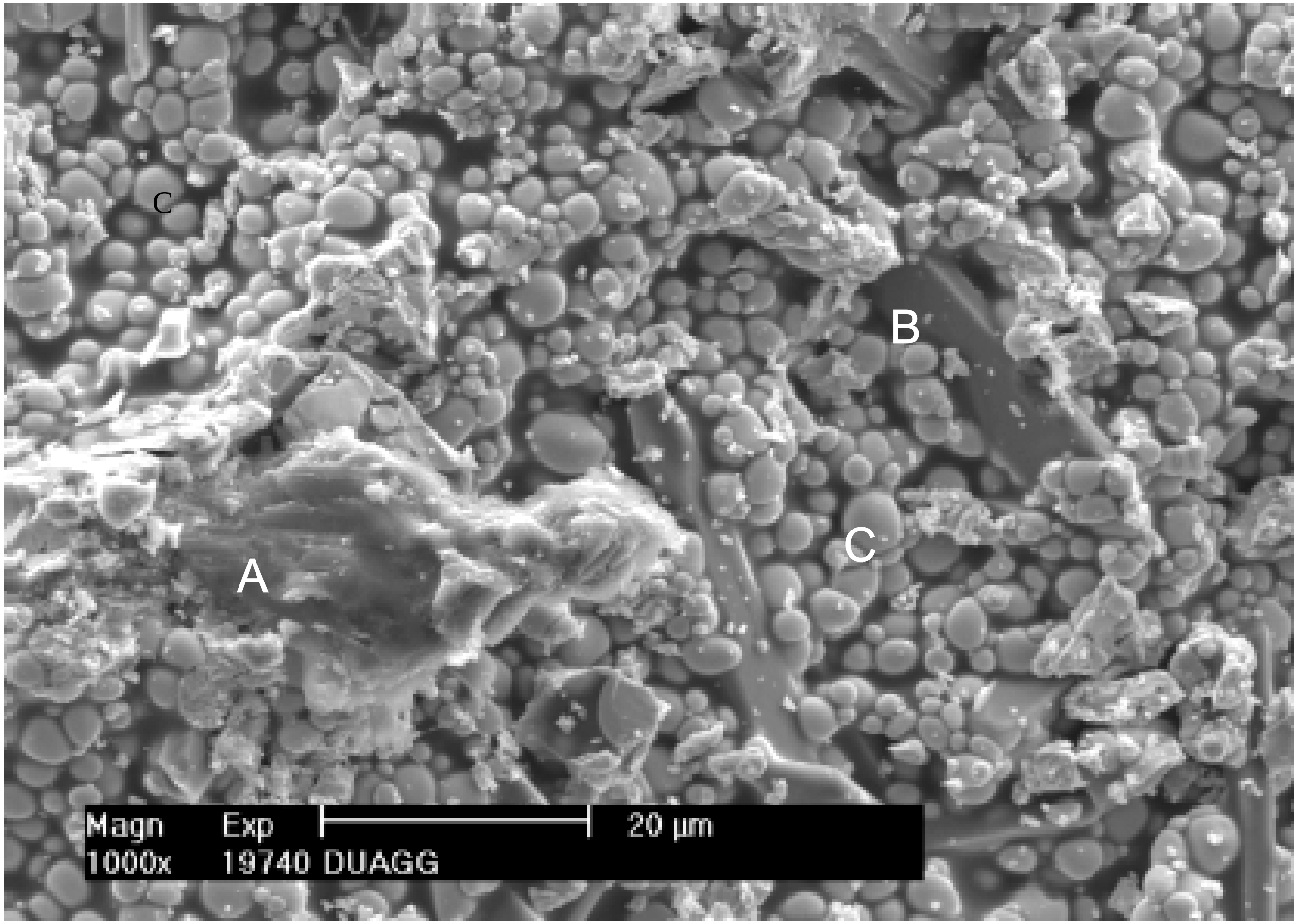
Current DUAGG Exposure Studies Using ASTM C289-94 Standard Test Method

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

(1) distilled water
(2) 1*N* 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

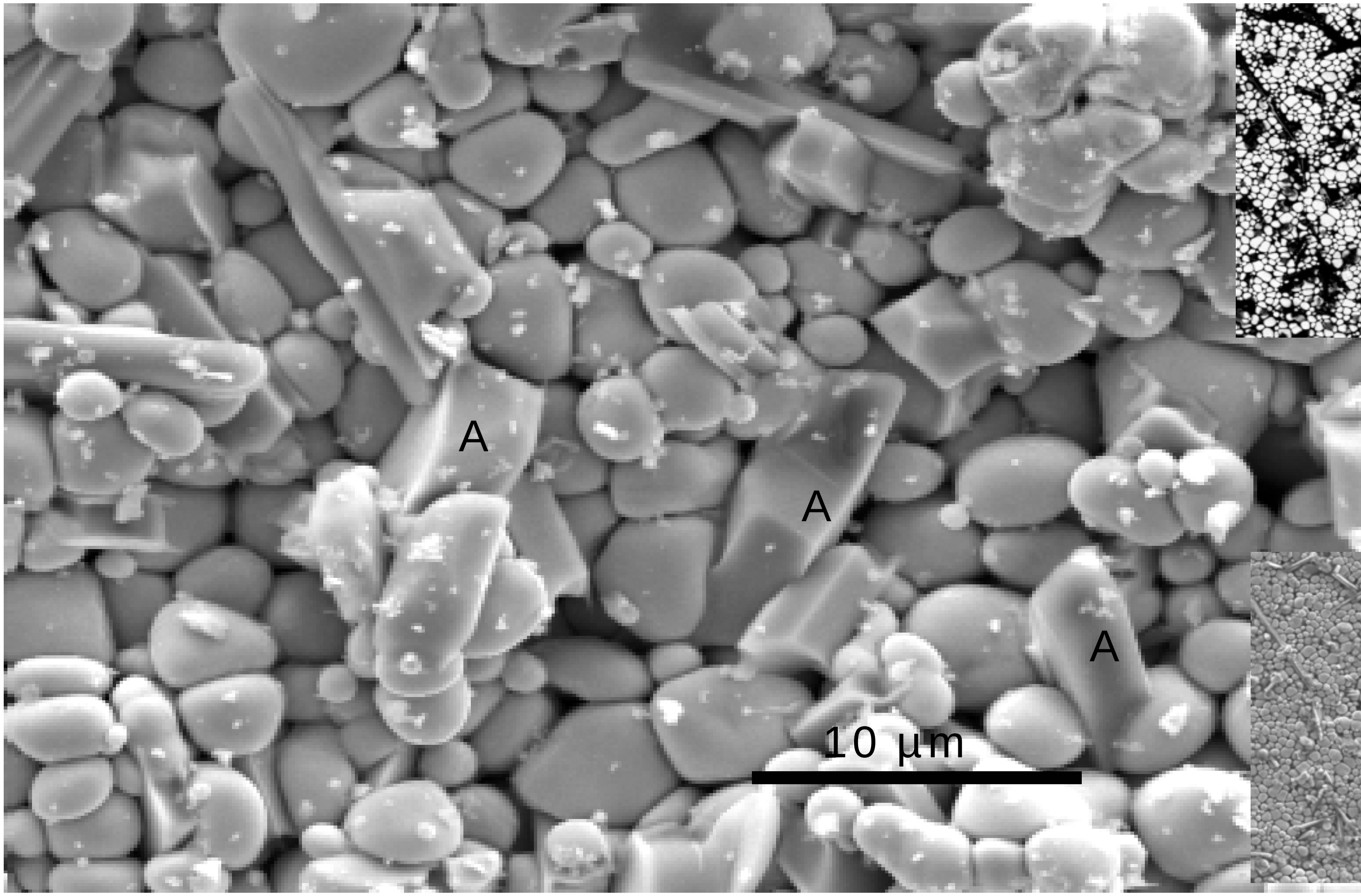


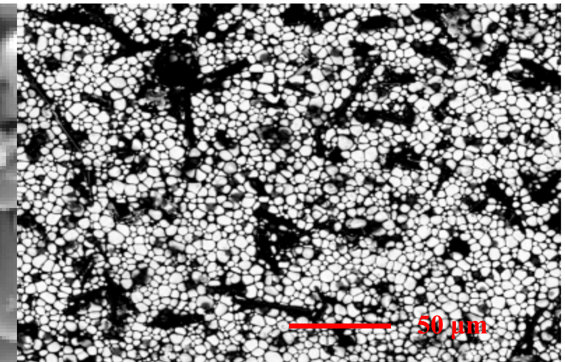
Detail of the surface (secondary electrons)

Particle A contains Al **Particle B contains Ti and some Mg**

Area C contains DUO_2 particles surrounded by dark basalt

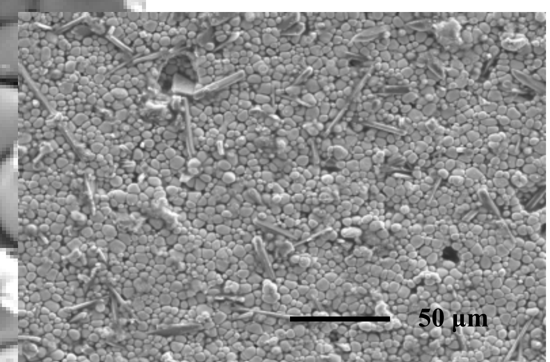
DUAGG After 6 Months in DI Water





Backscattered electrons

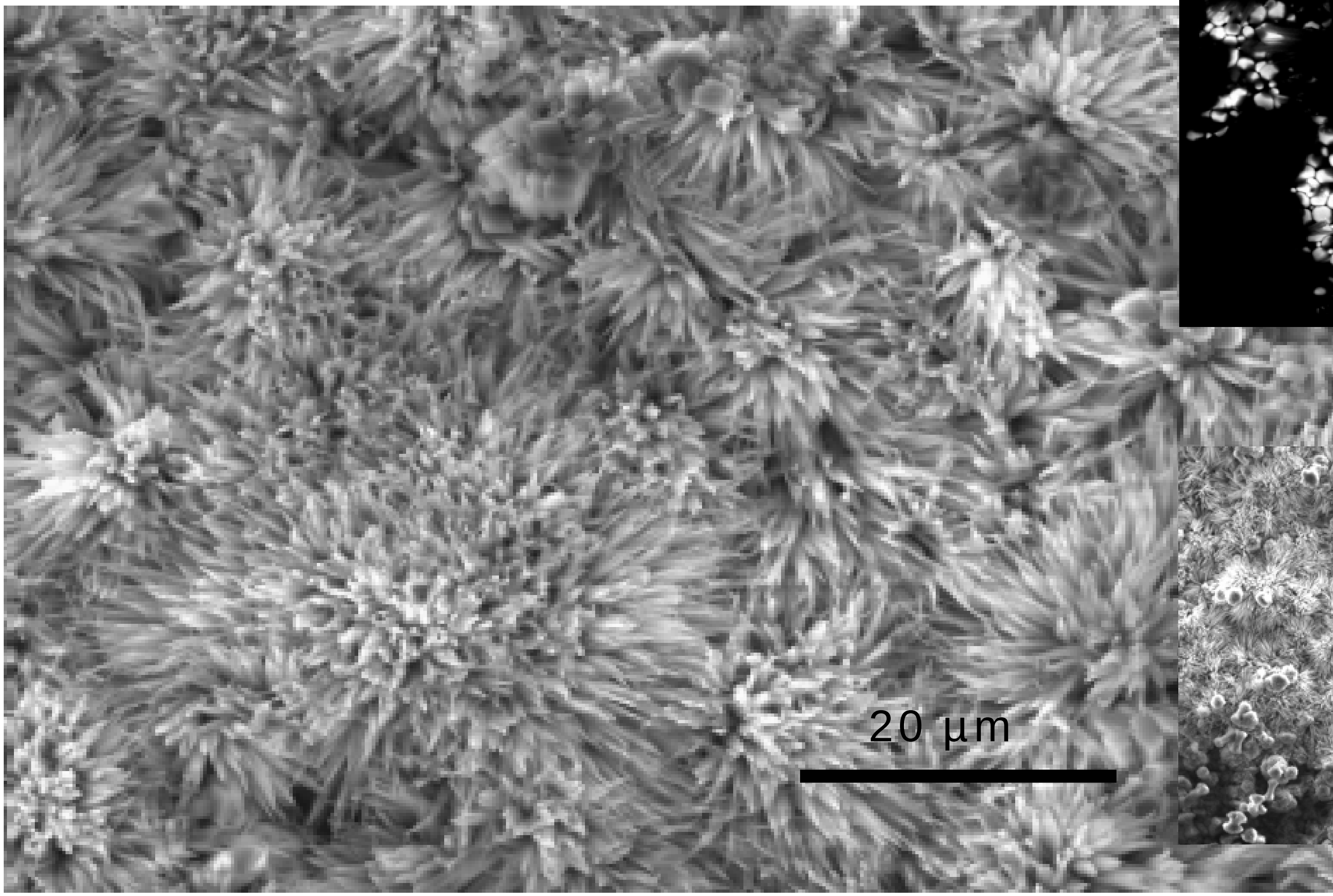
Secondary electrons

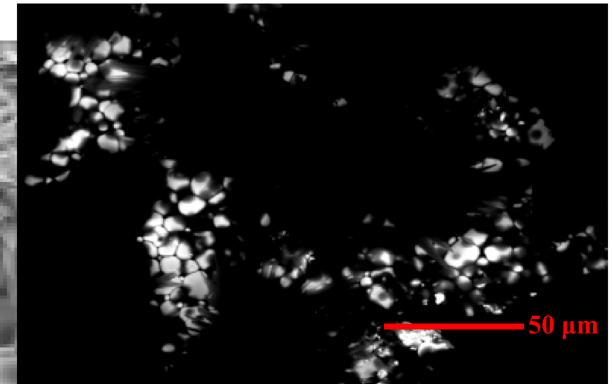


150°C — secondary electrons

Particles A contain Ti and some Mg

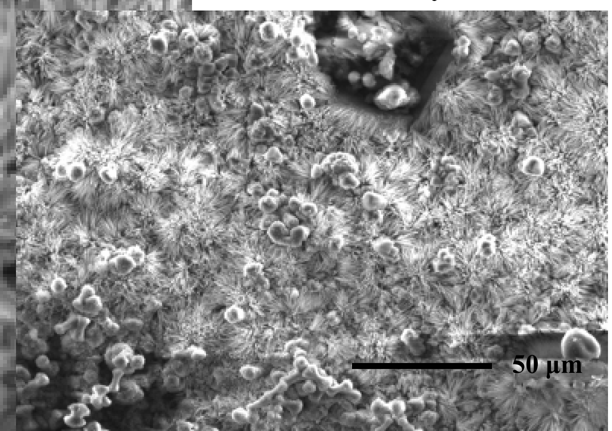
DUAGG After 6 Months in Cement Pore Solution





67°C—Backscattered electrons

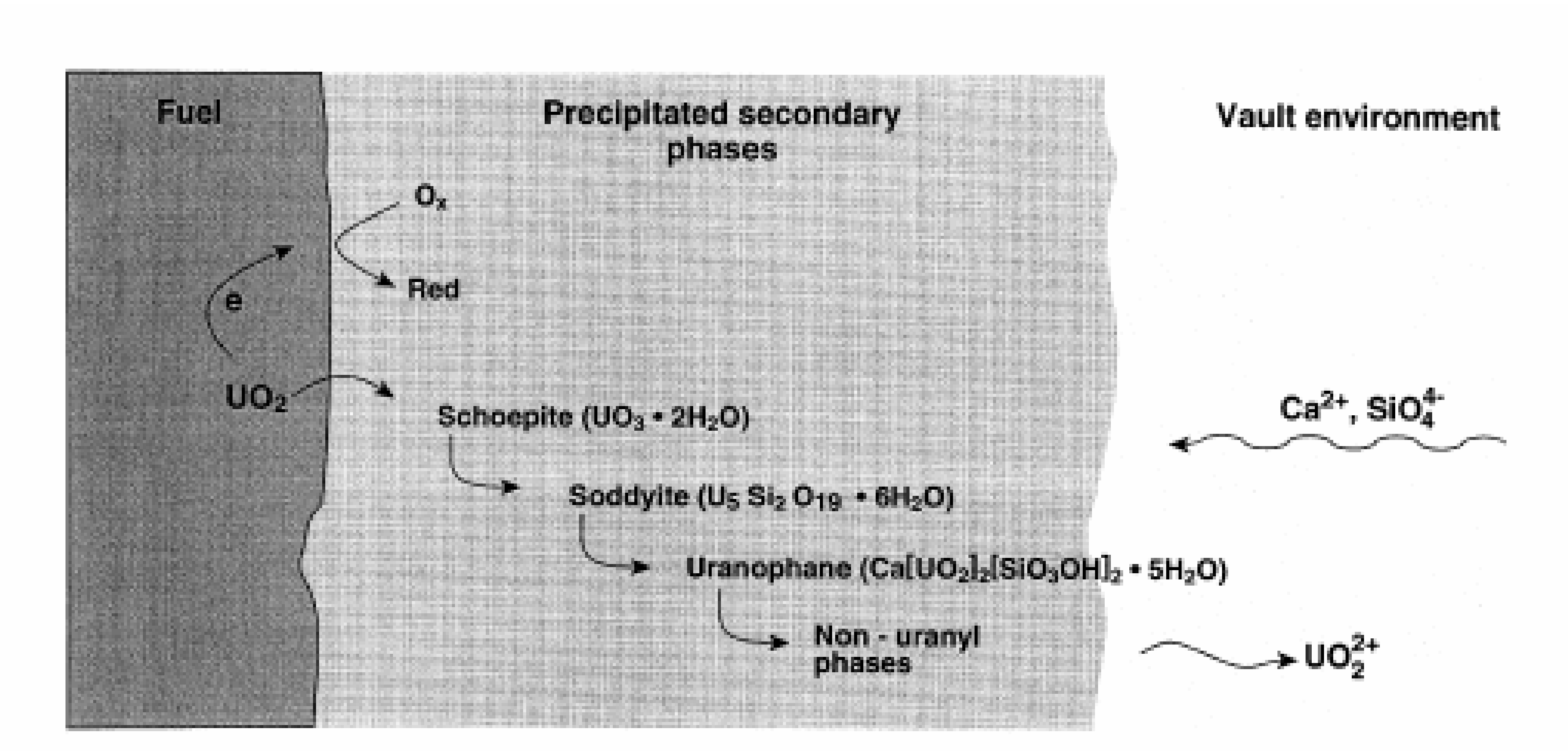
67°C — secondary electrons



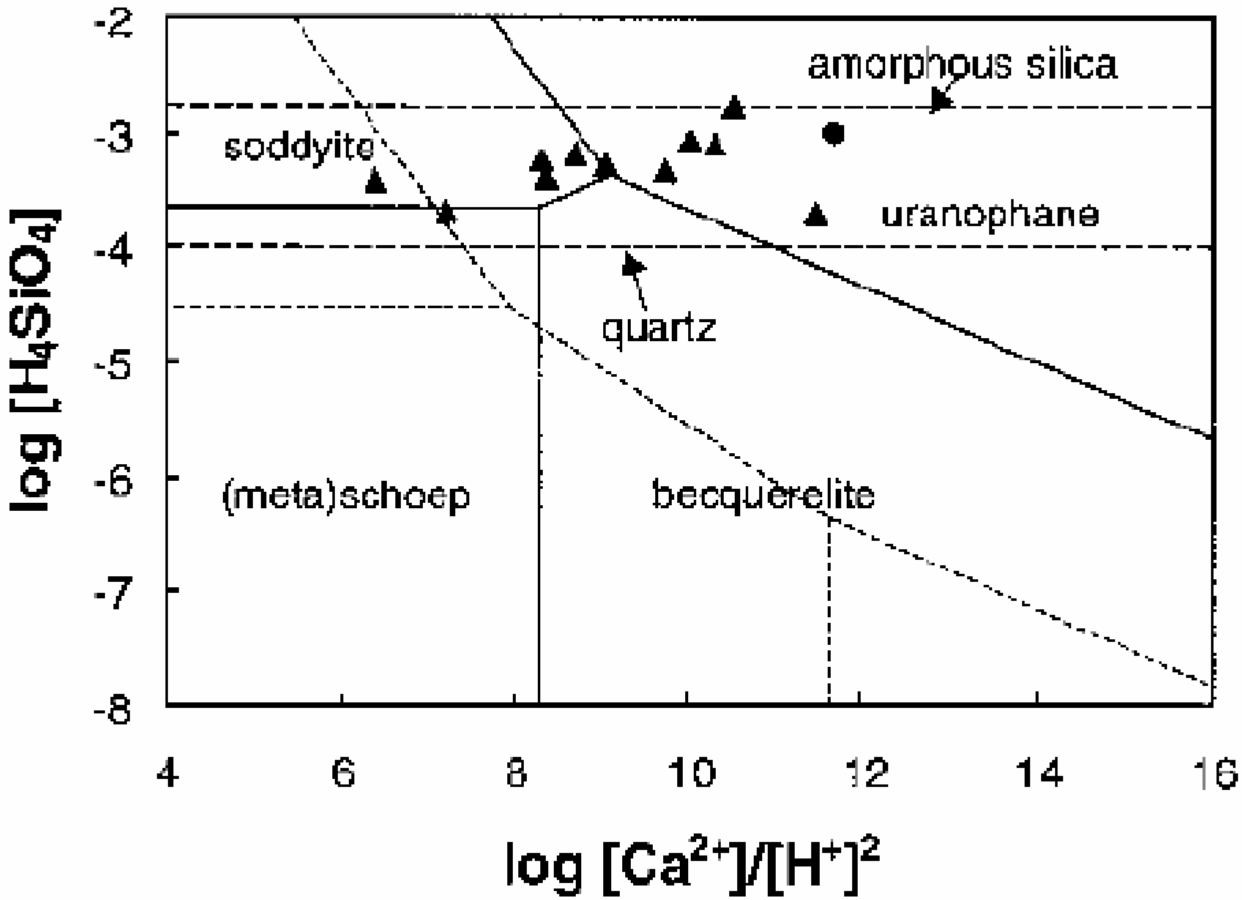
67°C — secondary electrons

Covered by $CaCO_3$ and needle-like crystals containing Ca, Si, and some Al

Silicates Form a Dense Diffusion Layer on the Surface of UO_2 Even under Oxidizing Conditions



High-Silica Forces Formation of Insoluble Uranium Silicates



Principal U(VI) Compounds

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

Uranyl phases	Formula	kJoule/mol[a]	kJoule/mol[b]
Metaschoepite	$[(UO_2)_8O_2(OH)_{12}]*(H_2O)_{10}$	–13,092.0	–13,092.0
Becquerelite	$Ca[(UO_2)_6O_4(OH)_6]*(H_2O)_8$	–10,324.7	–10,305.8
Rutherfordine	UO_2CO_3	–1,563.0	–1,563.0
Urancalcarite	$Ca_2[(UO_2)_3(CO_3)(OH)_6]*(H_2O)_3$	–6,036.7	–6,037.0
Sharpite	$Ca[(UO_2)_6(CO_3)_5(OH)_4]*(H_2O)_6$	–11,607.6	–11,601.1
Fontanite	$Ca[(UO_2)_3(CO_3)_4]*(H_2O)_3$	–6,524.7	–6,523.1
Liebigite	$Ca_2[(UO_2)(CO_3)_3]*(H_2O)_{11}$	–6,446.4	–6,468.6
Haiweeite	$Ca[(UO_2)_2(Si_2O_5)_3]*(H_2O)_5$	–9,367.2	–9,431.4
Ursilite	$Ca_4[(UO_2)_4(Si_2O_5)_5(OH)_6]*(H_2O)_{15}$	–20,377.4	–20,504.6
Soddyite	$[(UO_2)_2SiO_4]*(H_2O)_2$	–3,653.0	–3,658.0
Uranophane	$Ca[(UO_2)(SiO_3OH)]_2*(H_2O)_5$	–6,192.3	–6,210.6

[a] Chen 1999 [b] Finch 1997

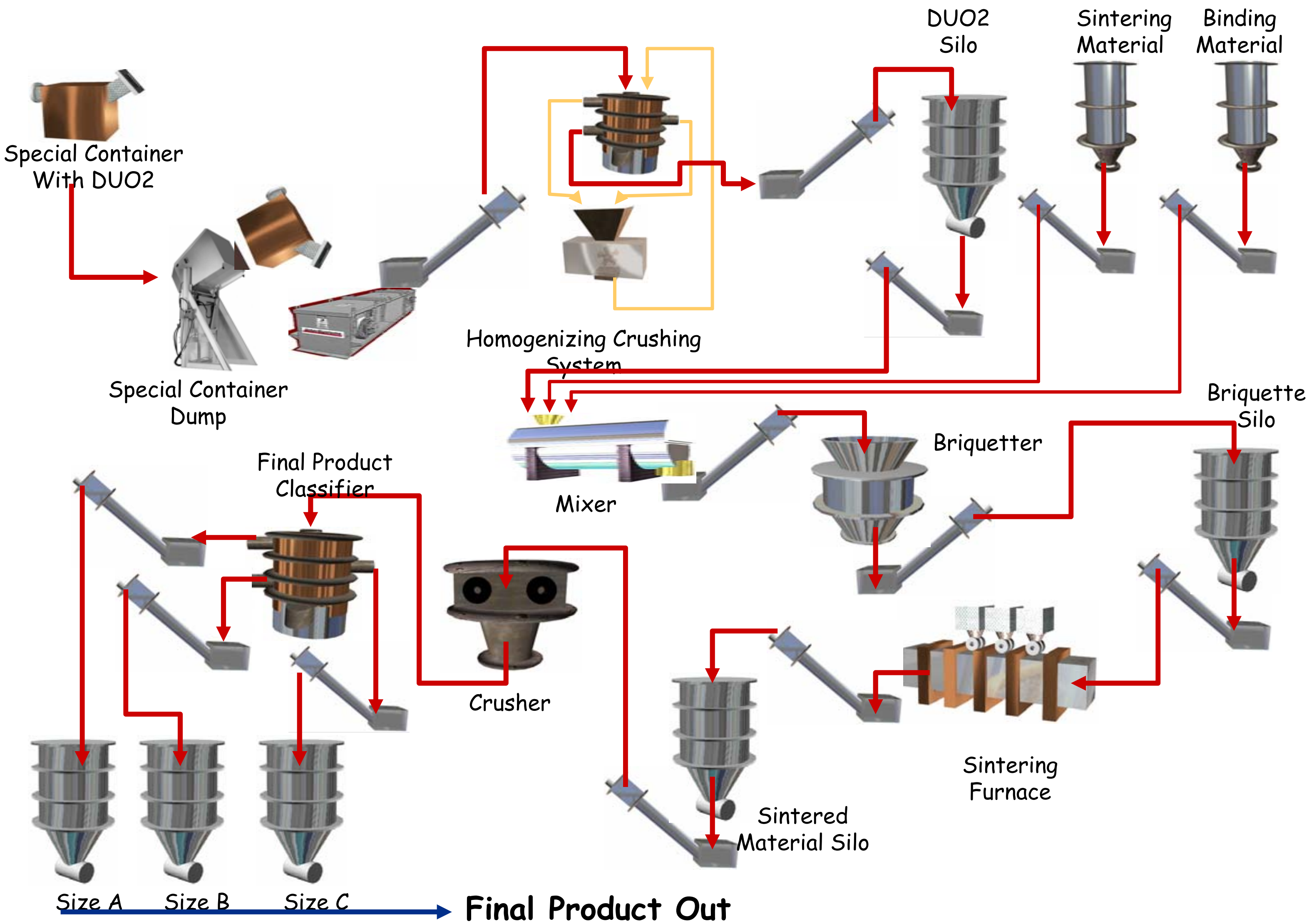
Conclusions on DUAGG Testing

- 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**

Conceptual Fabrication of DUAGG



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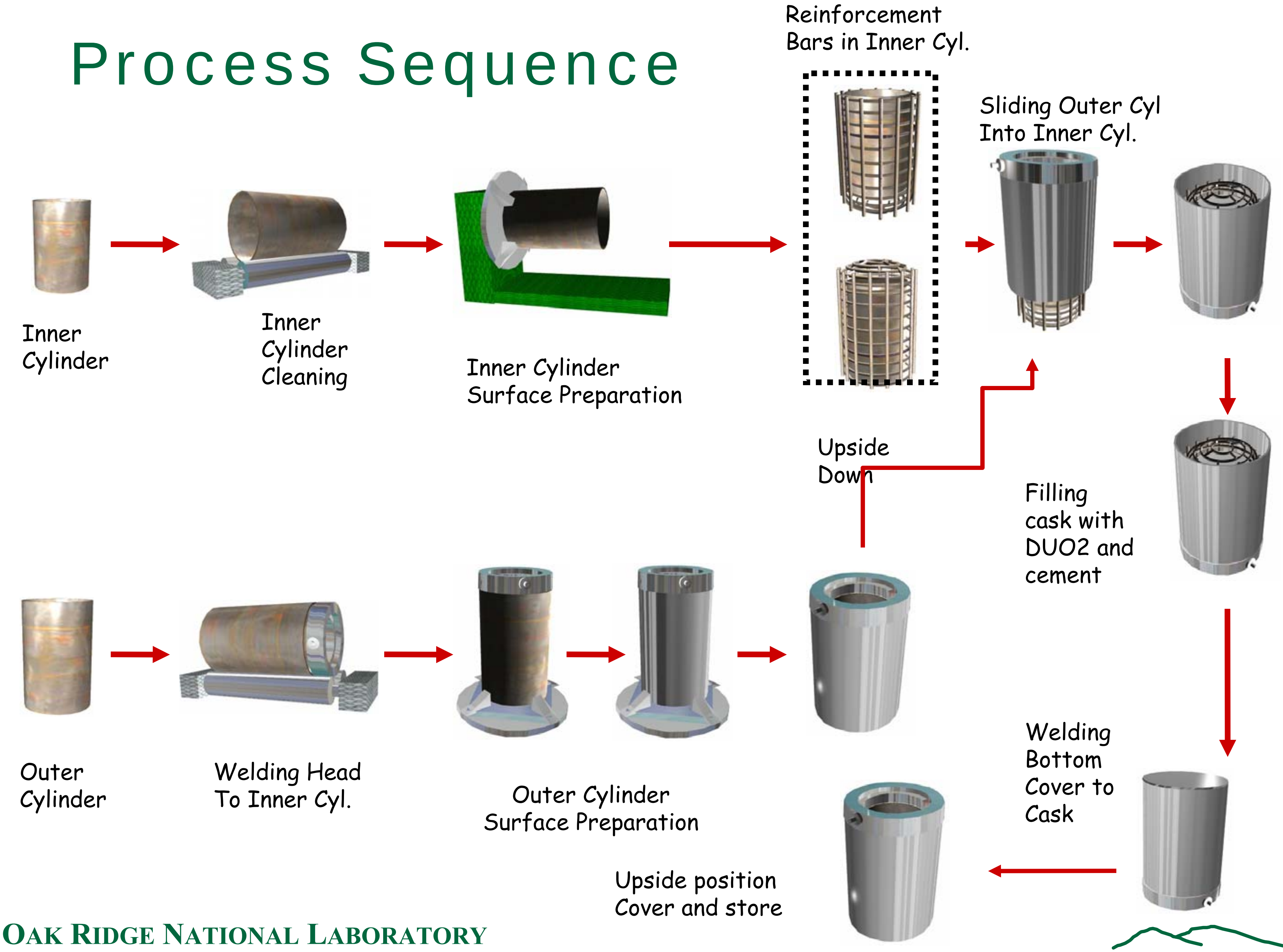
Conclusions of DUAGG Price Study

- **Labor is primary cost**
  - **Reduce by privatization**
  - **Reduce by integrating with DUF_6 conversion**
  - **Reduce labor intensive processing steps**
- **Cost of Producing DUAGG, $138,000/cask (62 tons DUAGG per cask)**

Preconception Cask Design and Fabrication Cost Study

CONSTOR Cask Fabrication used as Baseline

Process Sequence

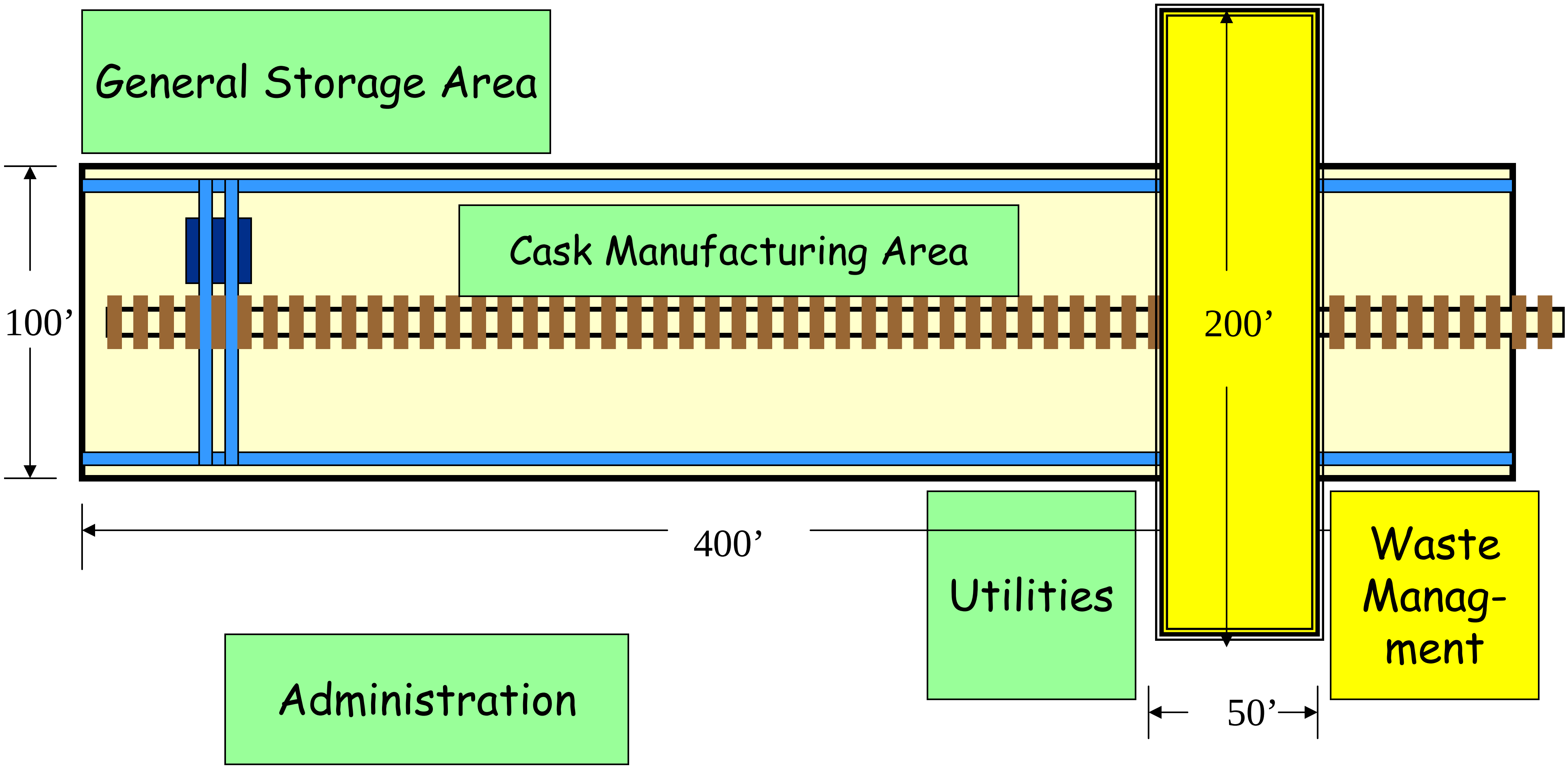


Some Fabrication Steps

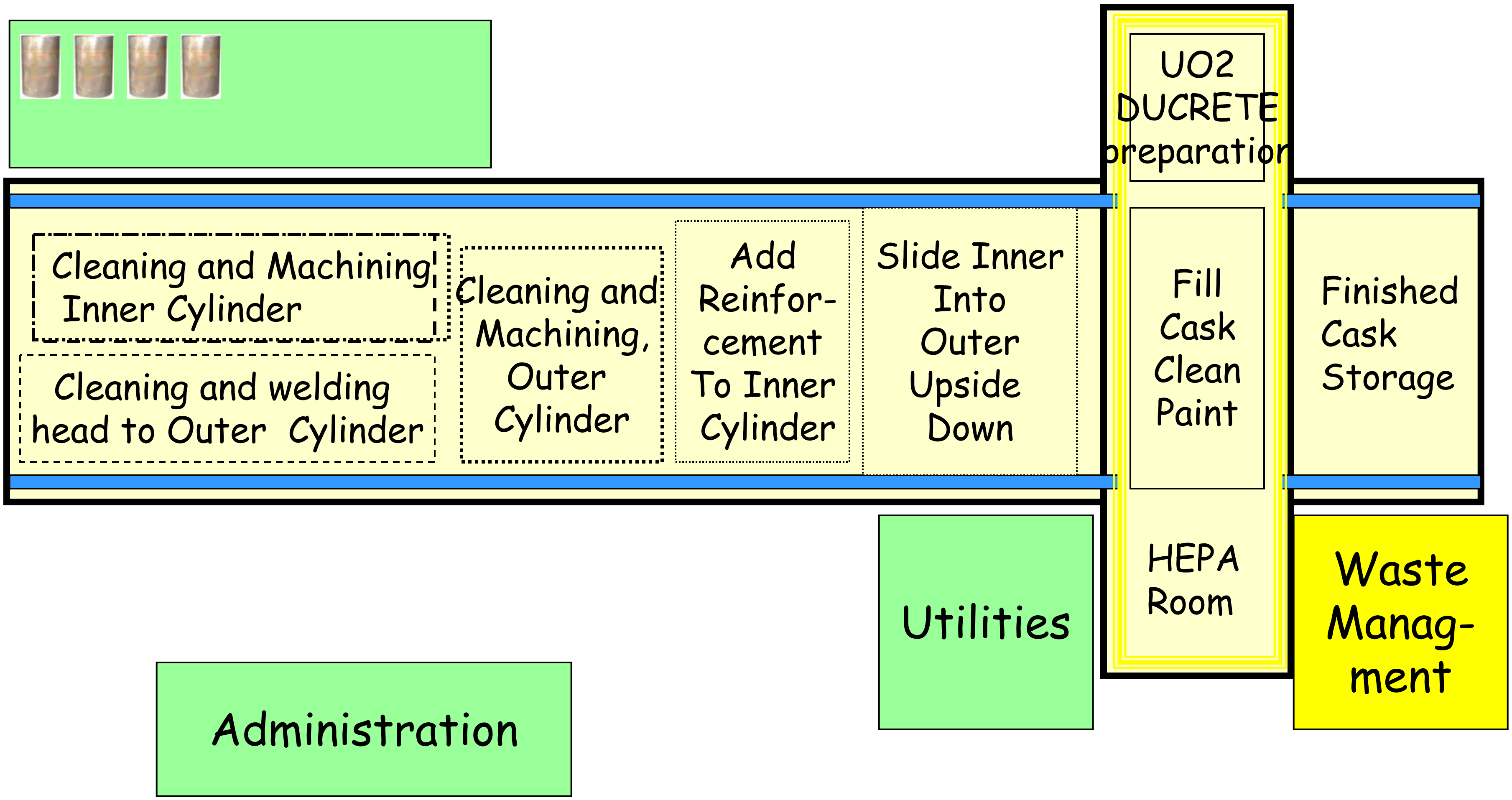
Assumptions

- 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



Process Stage Distribution



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 : 13 * 2080 hr/yr * $70/hr
  : $1,900K/yr

- Administration

  Secretary : 1*2080 hr/yr*$30/hr = $ 62.4K/yr

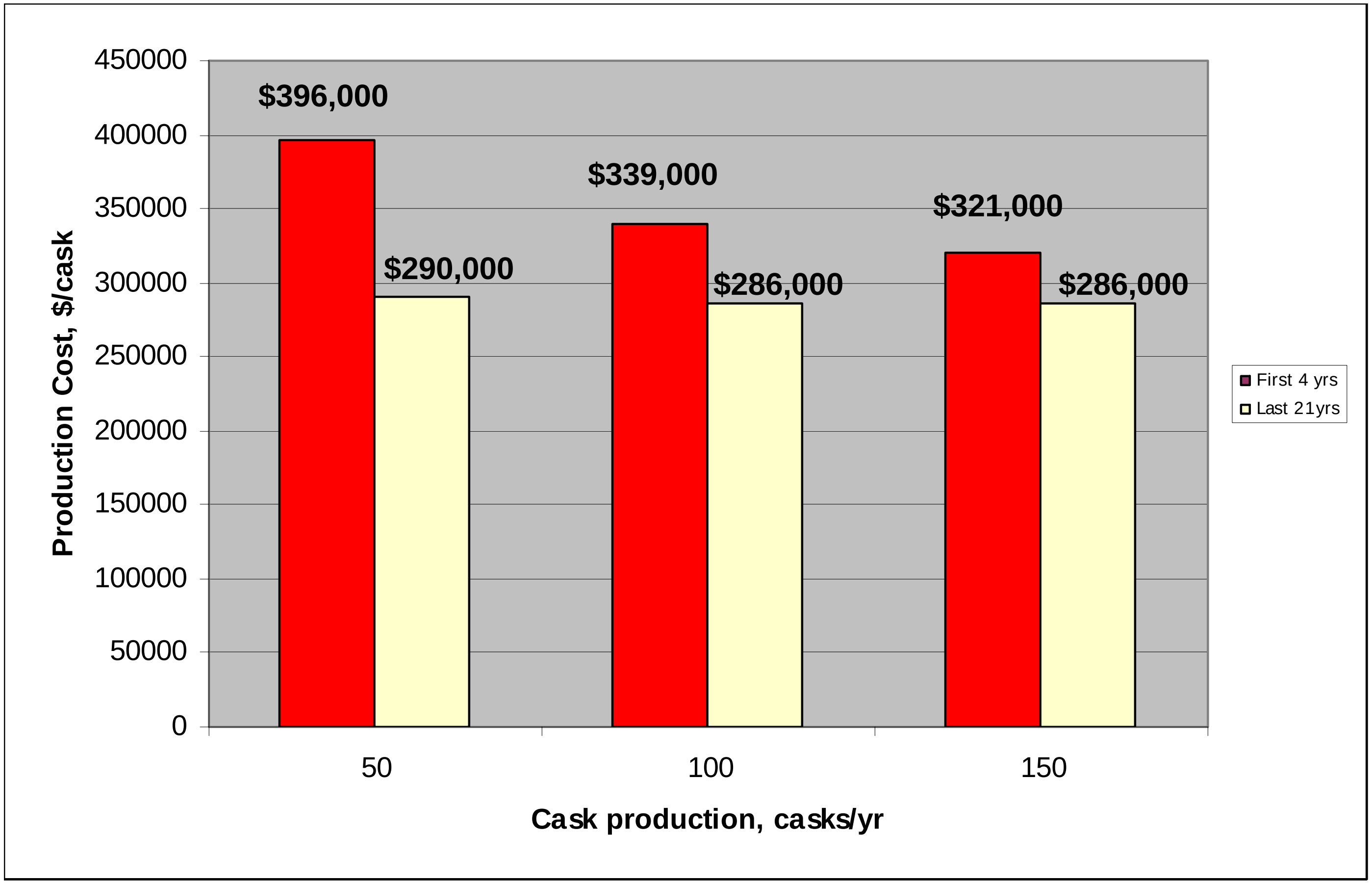
  Shift superintendent : 1*2080 hr/yr *$80/hr = $166.4K/yr

  General Manager : 1*2080 hr/yr*$90/hr = $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%

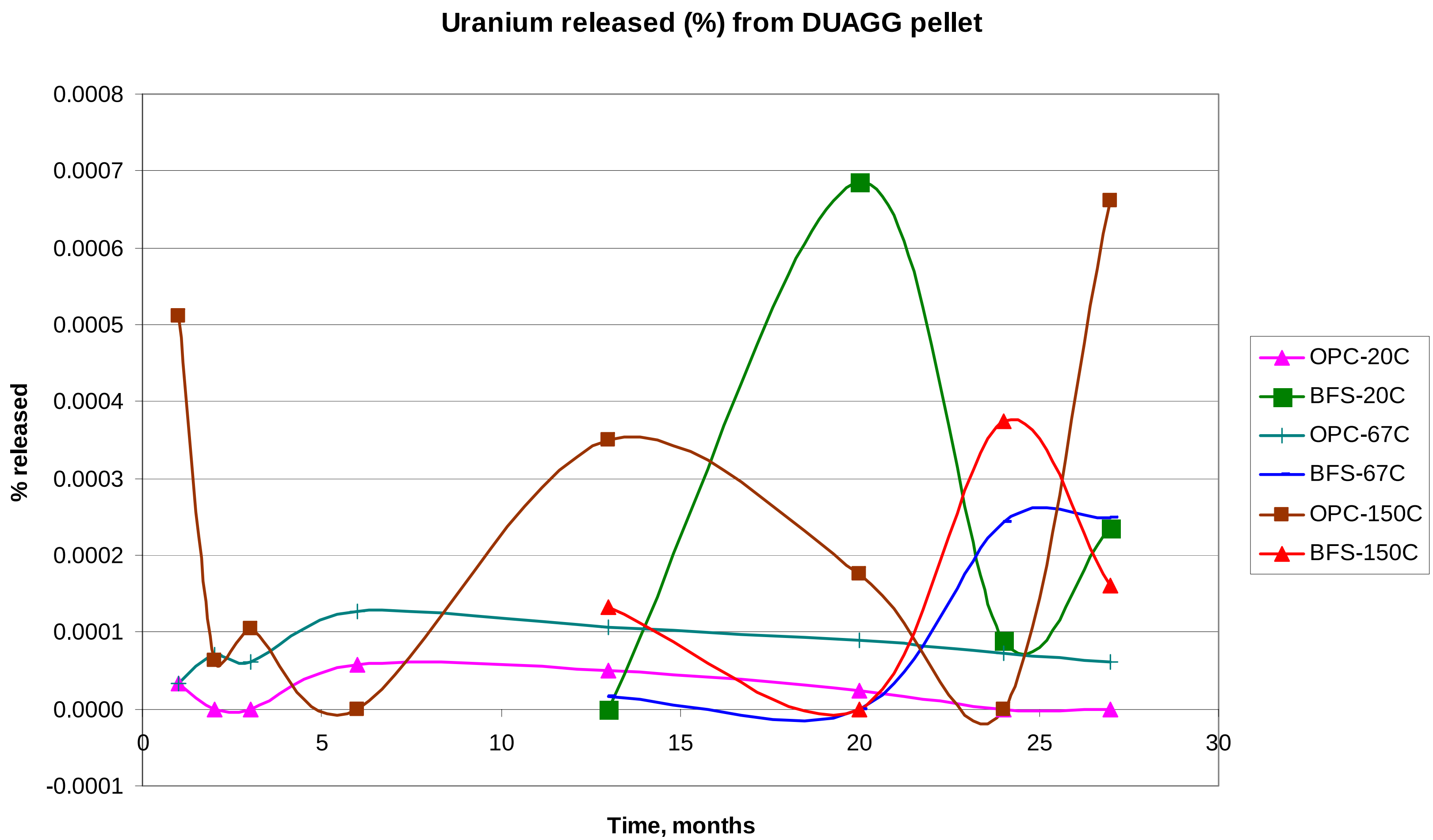
US Questions

- **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**

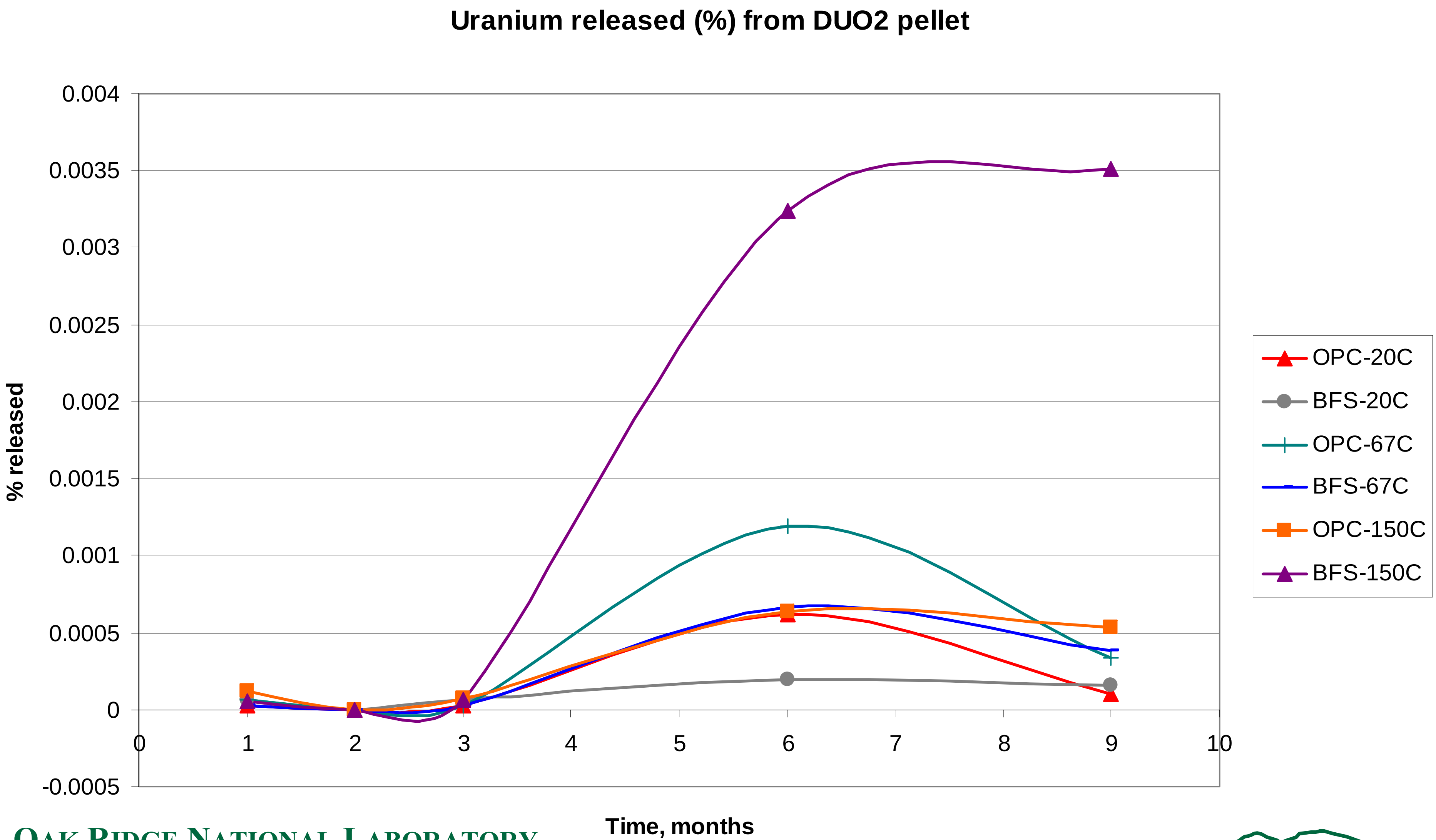
Extra Slides

Support Discussions and Questions

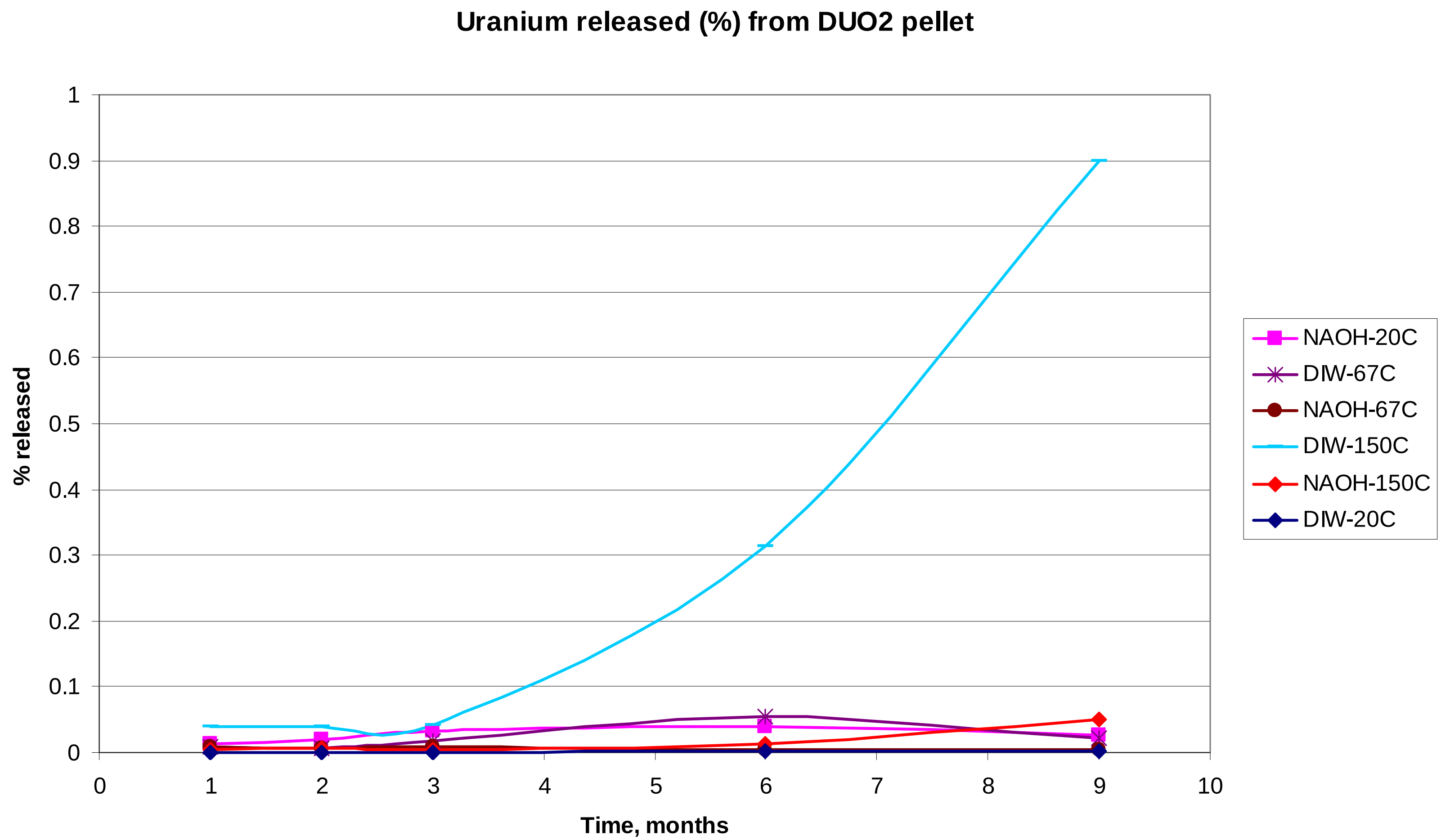
U released from DUAGG into Cement and Blast-Furnace Slag Porewater



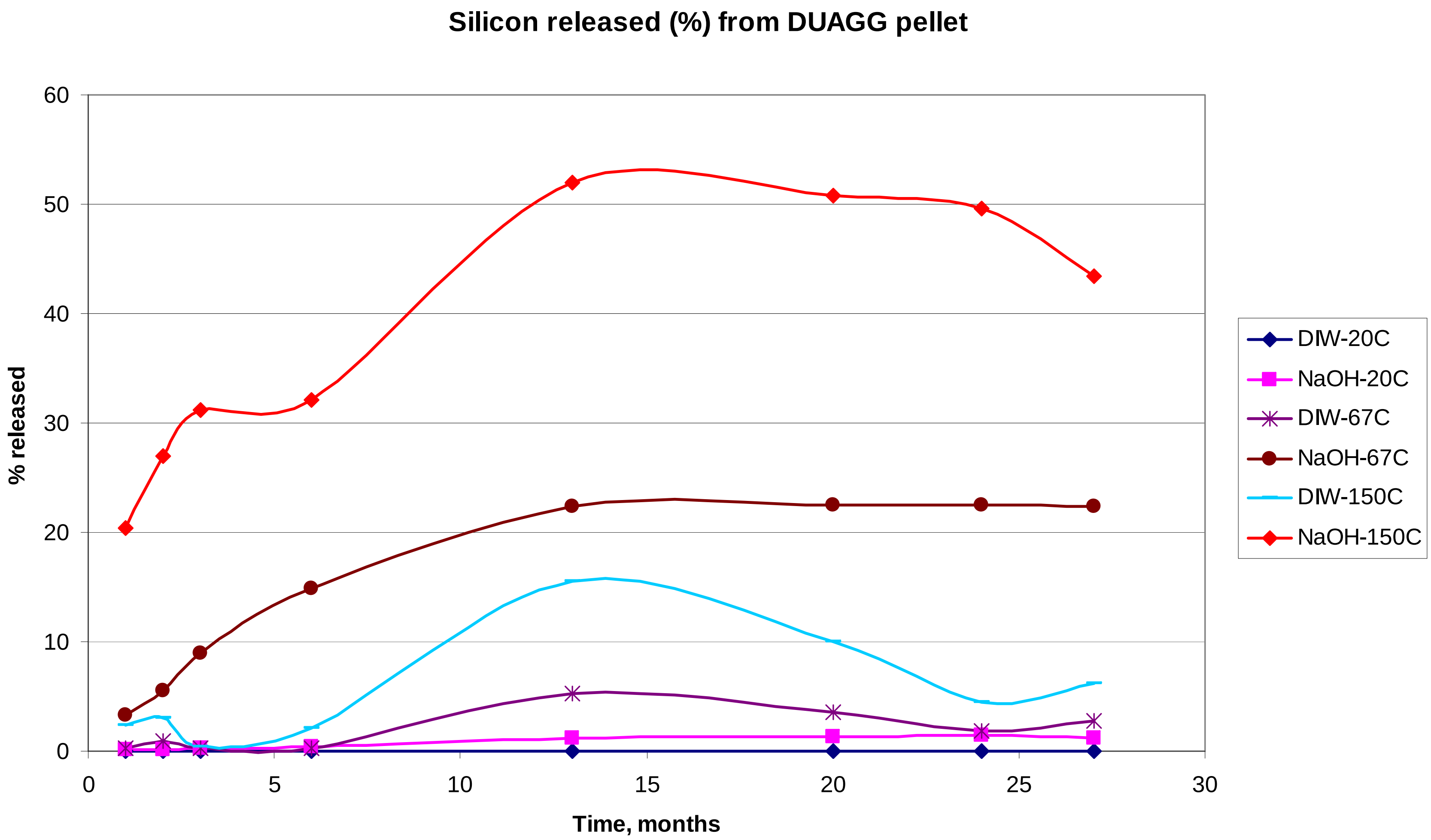
U Released from High-fired UO_2 Fuel Pellet into Cement and Slag Porewater



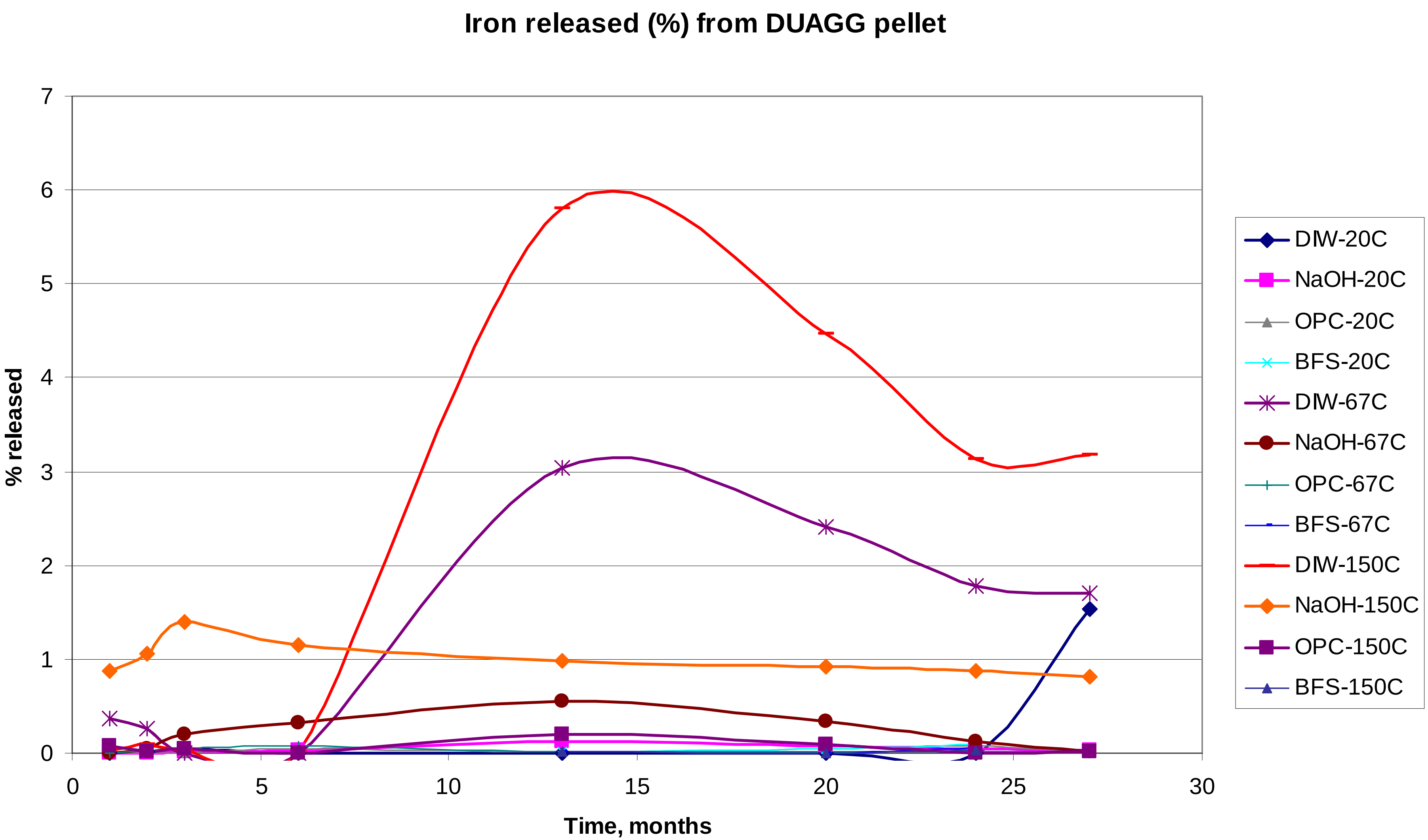
U Released from High-Fired UO_2 Fuel Pellet into 1 N NaOH and Distilled Water



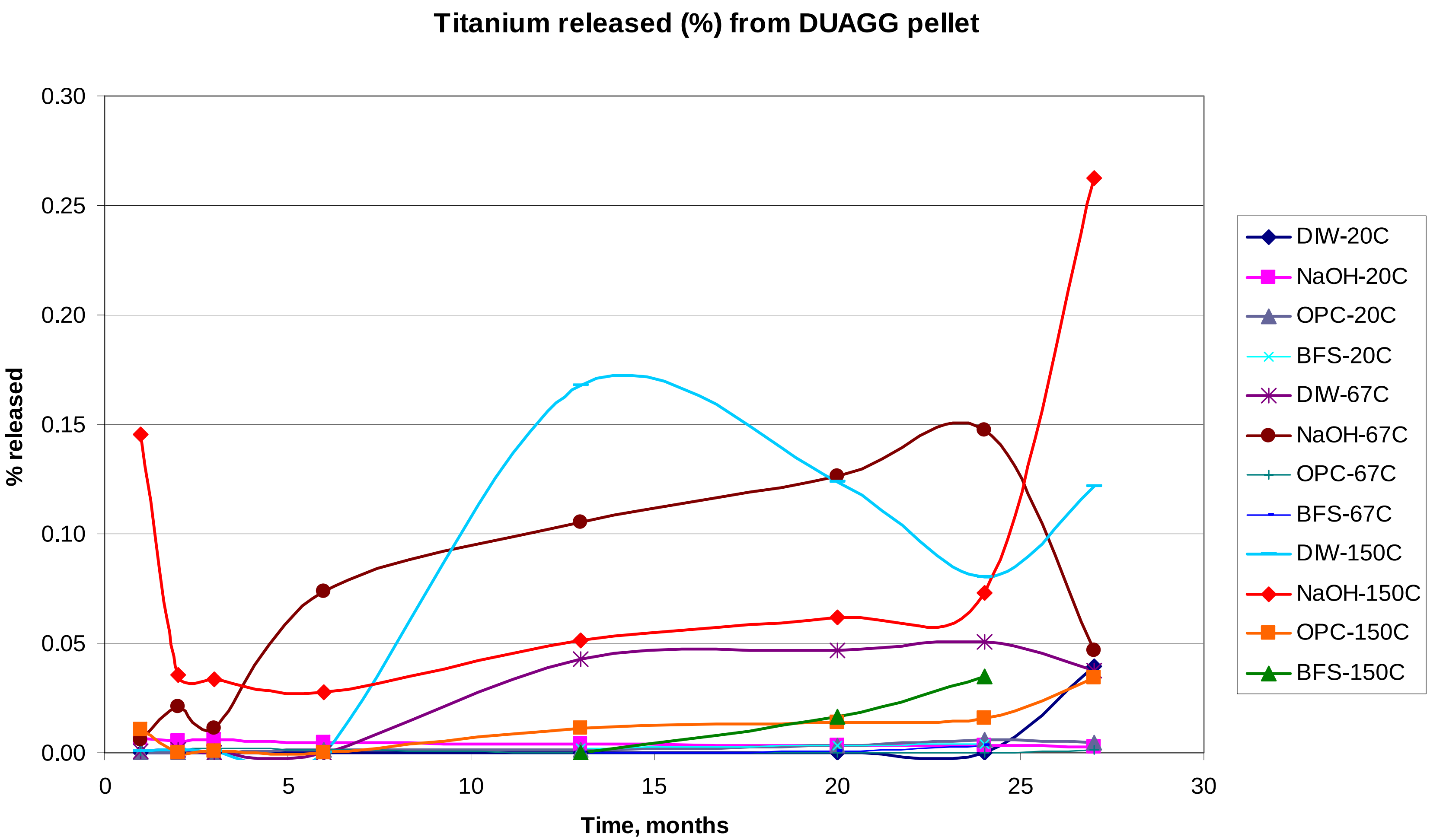
Si Released from DUAGG into 1N NaOH and Distilled Water



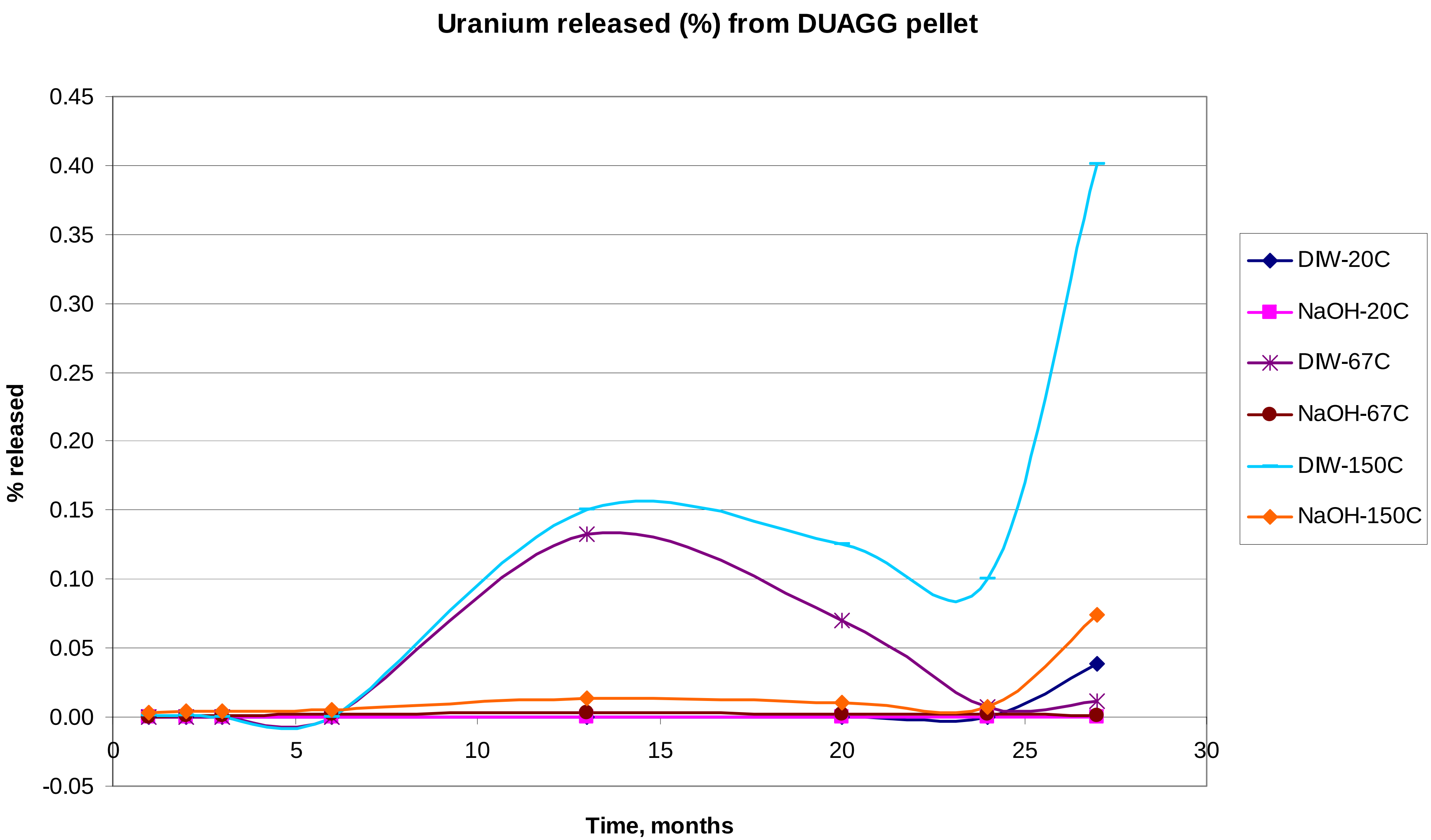
Iron Release



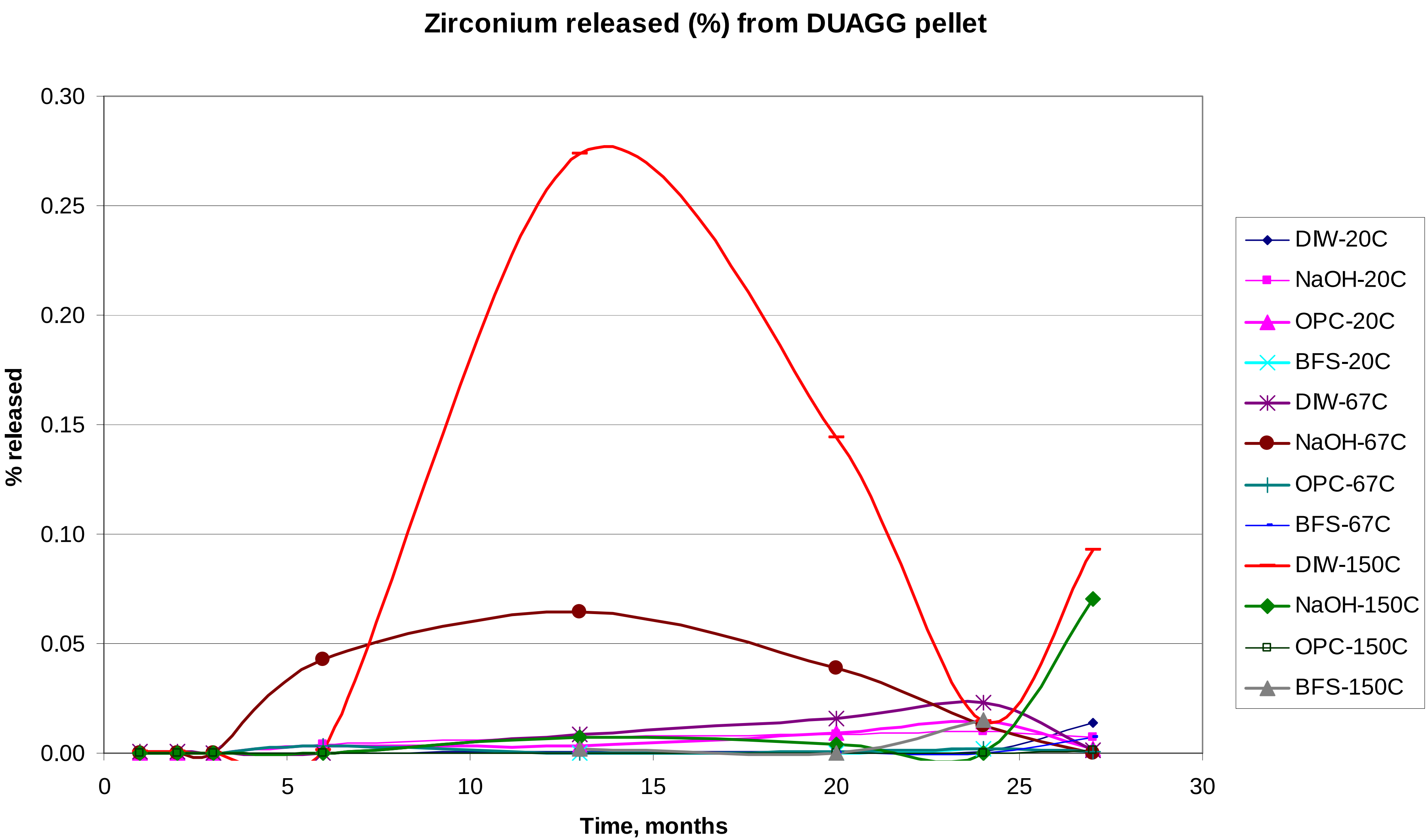
Titanium Release



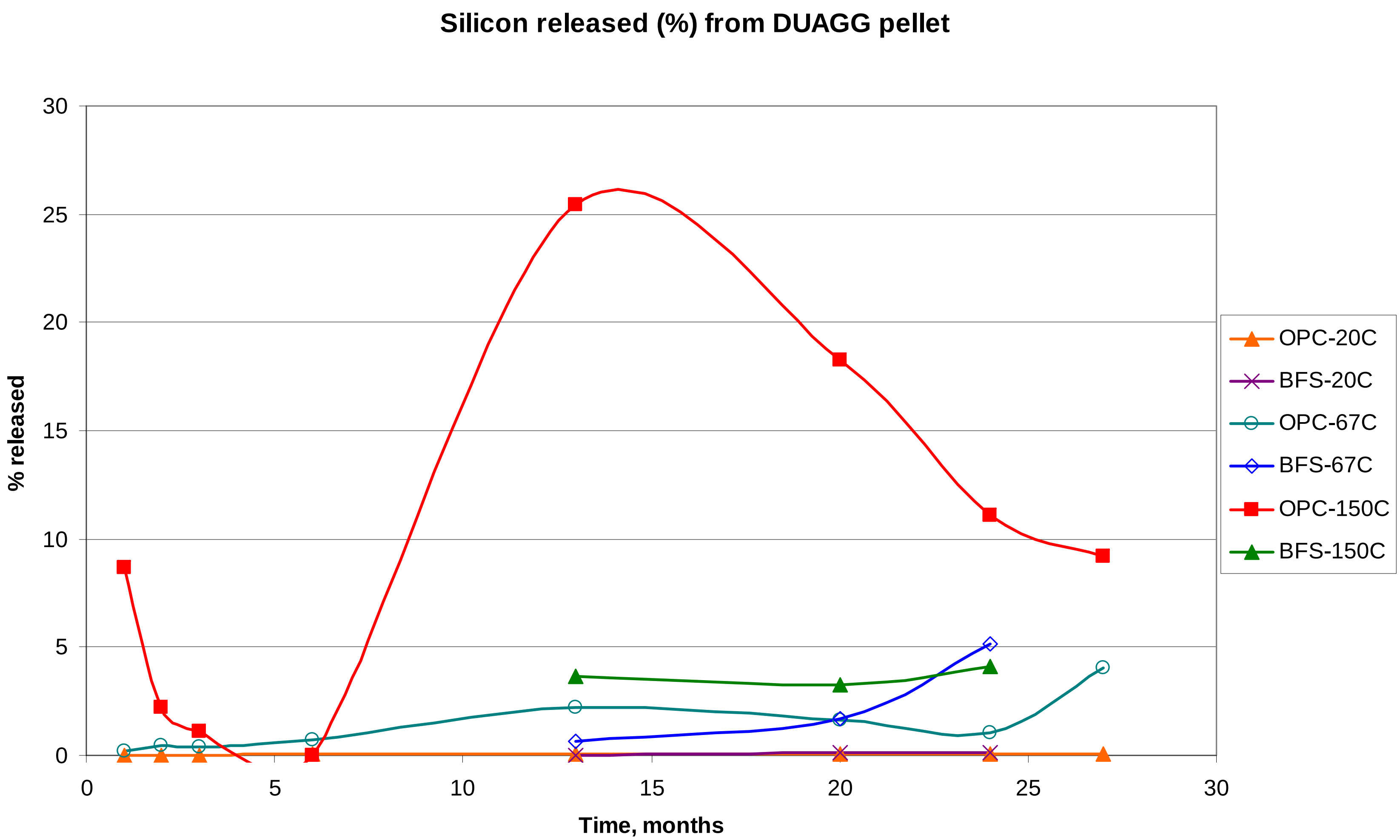
U Released from DUAGG into 1N NaOH and Distilled Water



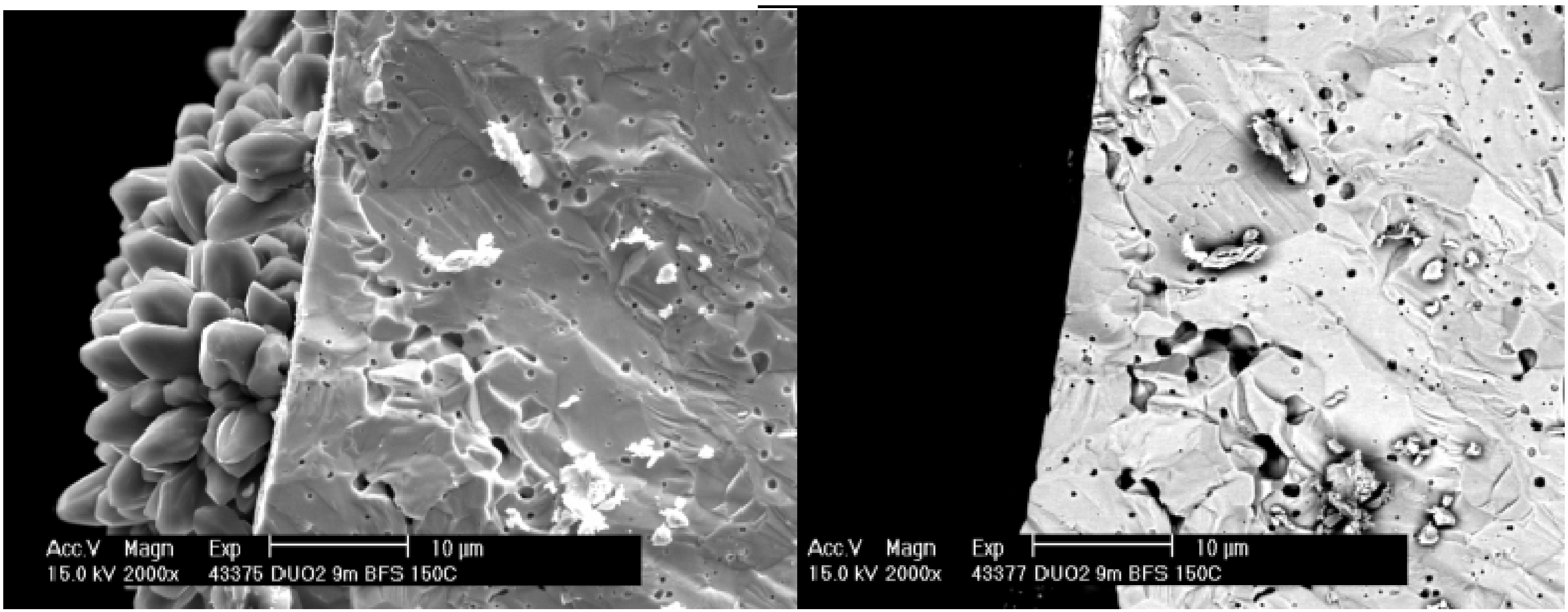
Zirconium Release



Si released from DUAGG into Cement and Blast-Furnace Slag Porewater

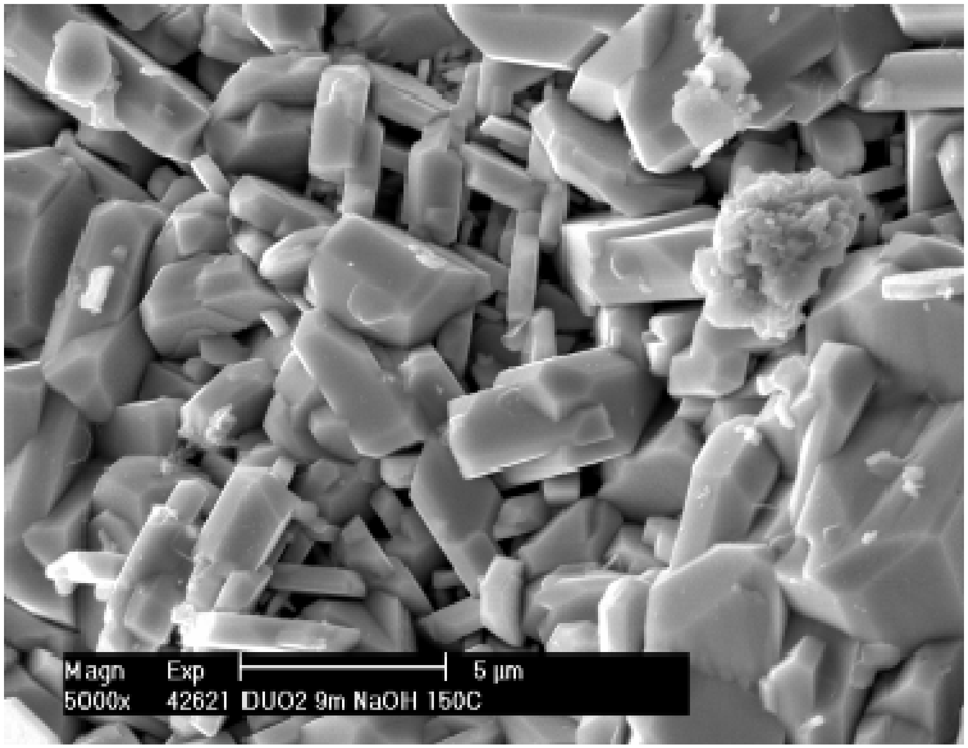


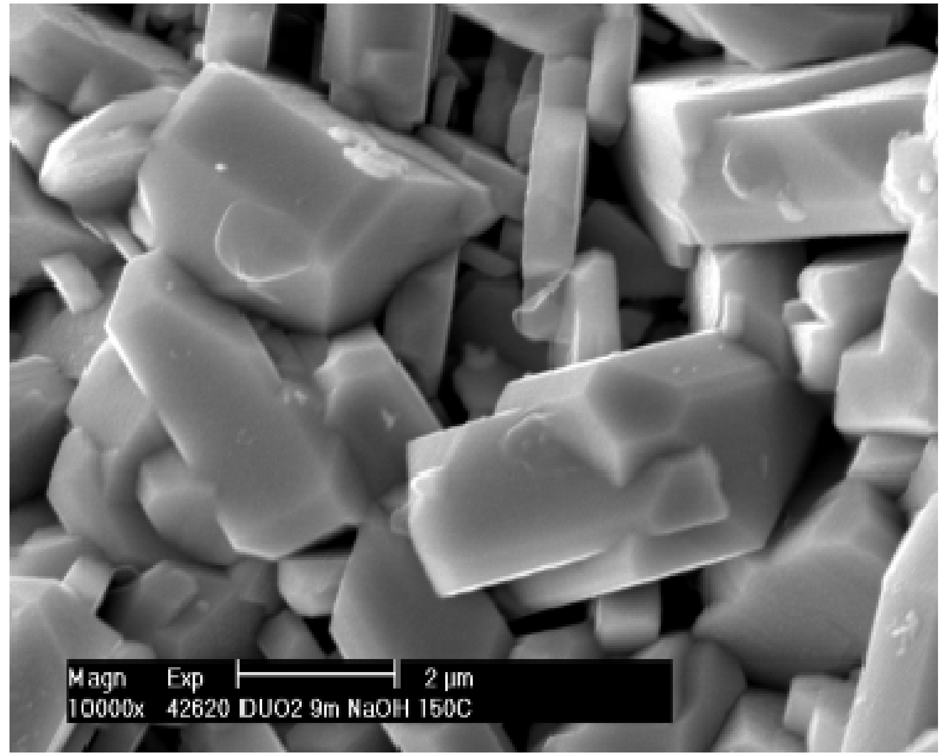
High-Fired DUO_2 Fuel Pellet in 60% OPC + 40% BFS porewater at 67˚C for 9 Months



Fracture of the cylinder - $CaCO_3$ visible on the outside surface

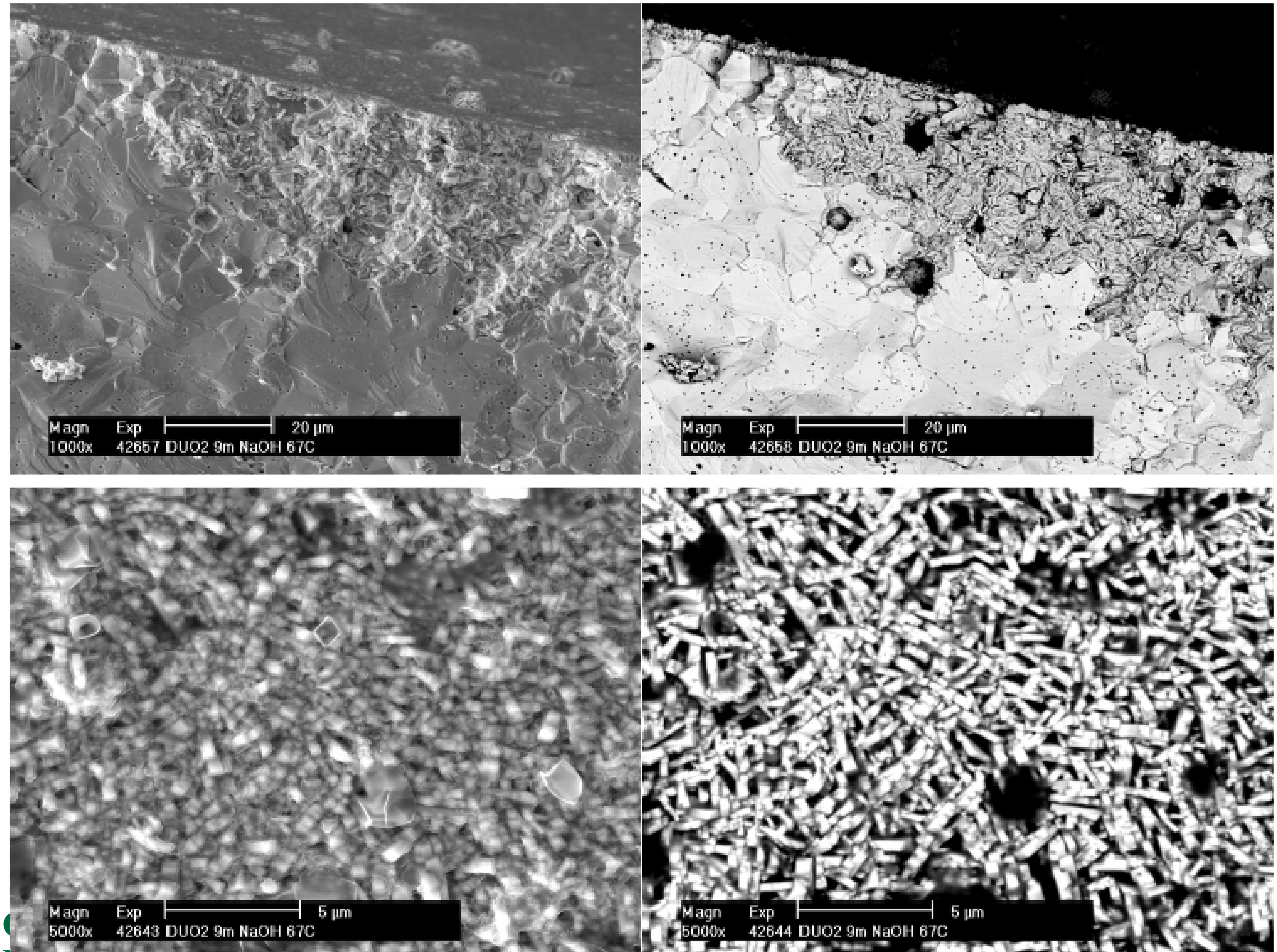
High-Fired DUO_2 Fuel Pellets in 1*N* NaOH Solution at 150˚C for 9 Months





Side of the exposed fuel-pellet shows grains of DUO_2 that are not cohesive

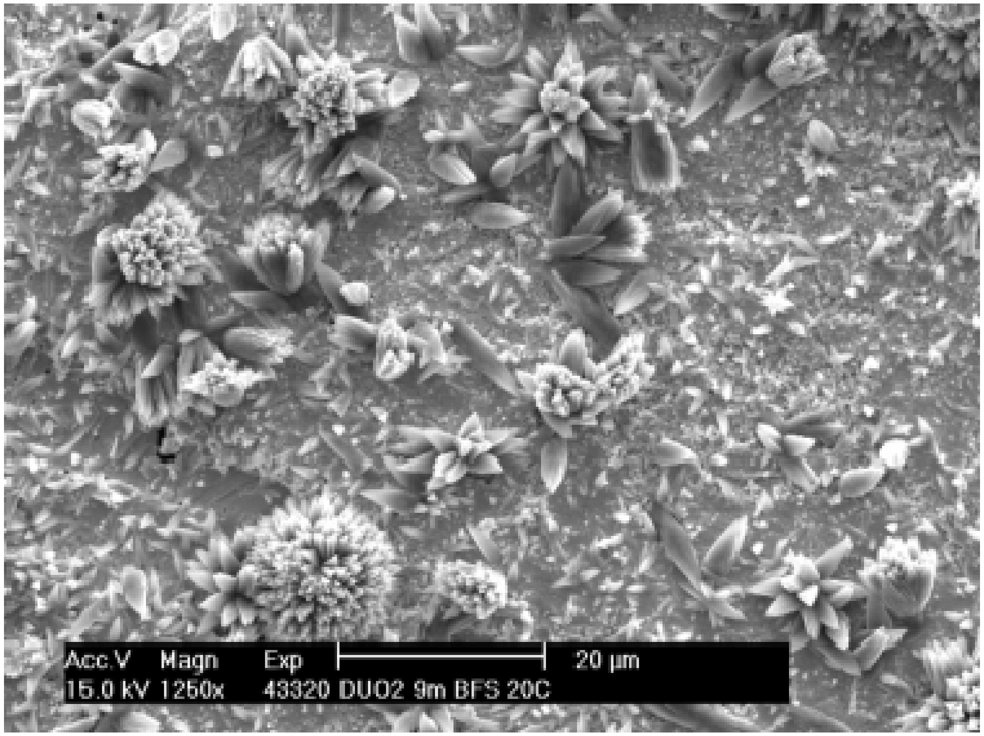
High-Fired DUO_2 Fuel Pellets in 1*N* NaOH Solution at 67˚C for 9 Months

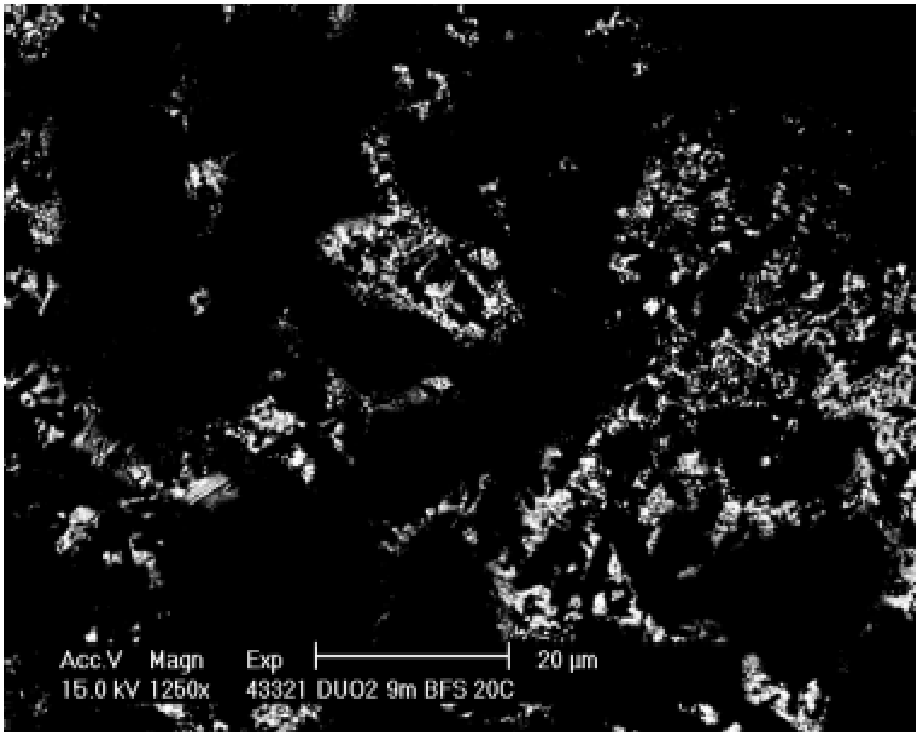


Fracture

Side

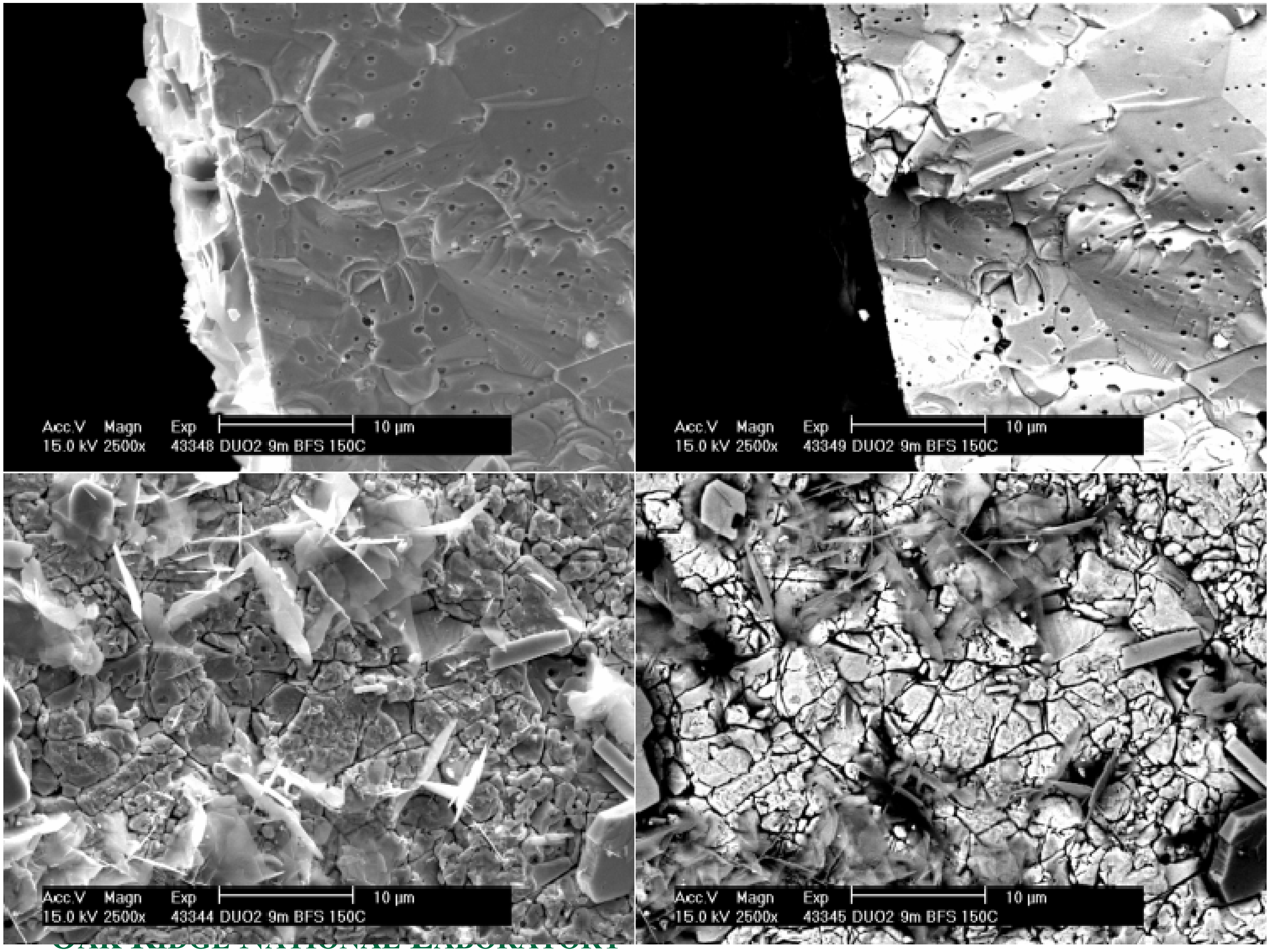
High-Fired DUO_2 Fuel Pellet in 60% OPC + 40% BFS Porewater at 20˚C for 9 Months





Side view with $CaCO_3$ deposits

High-Fired DUO_2 Fuel Pellet in 60% OPC + 40% BFS Porewater at 150˚C for 9 months



Fracture

Top