Depleted Uranium as Aggregate in Concrete Shielding Material

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State Unitary Enterprise, and Russian Research Institute of Chemical Technology

Conclusions

- Combinations of gamma-absorbing depleted uranium (DU) and neutron-absorbing hydrated binders are shown to effectively reduce the size and weight of storage, transport, and disposal casks

- DUCRETE™ will become one of the materials of choice for advanced spent nuclear fuel (SNF) casks
  - Requires the demonstration of low-cost fabrication processes
  - Requires the demonstration of long-term durability under expected service conditions

TM = trademark, patented technology

Presentation Outline

- Programmatic background
- Description of technology
- Summary of previous accomplishments
- Description of current studies and results
- Conclusions

Vision and Mission of the DU Uses R&D Project

- Reduce DU disposition costs
- Consume the inventory of DU by using it in nuclear shielding applications
- Bring advanced DU shielding technologies to the level of demonstrated technical success and readiness for full-scale deployment

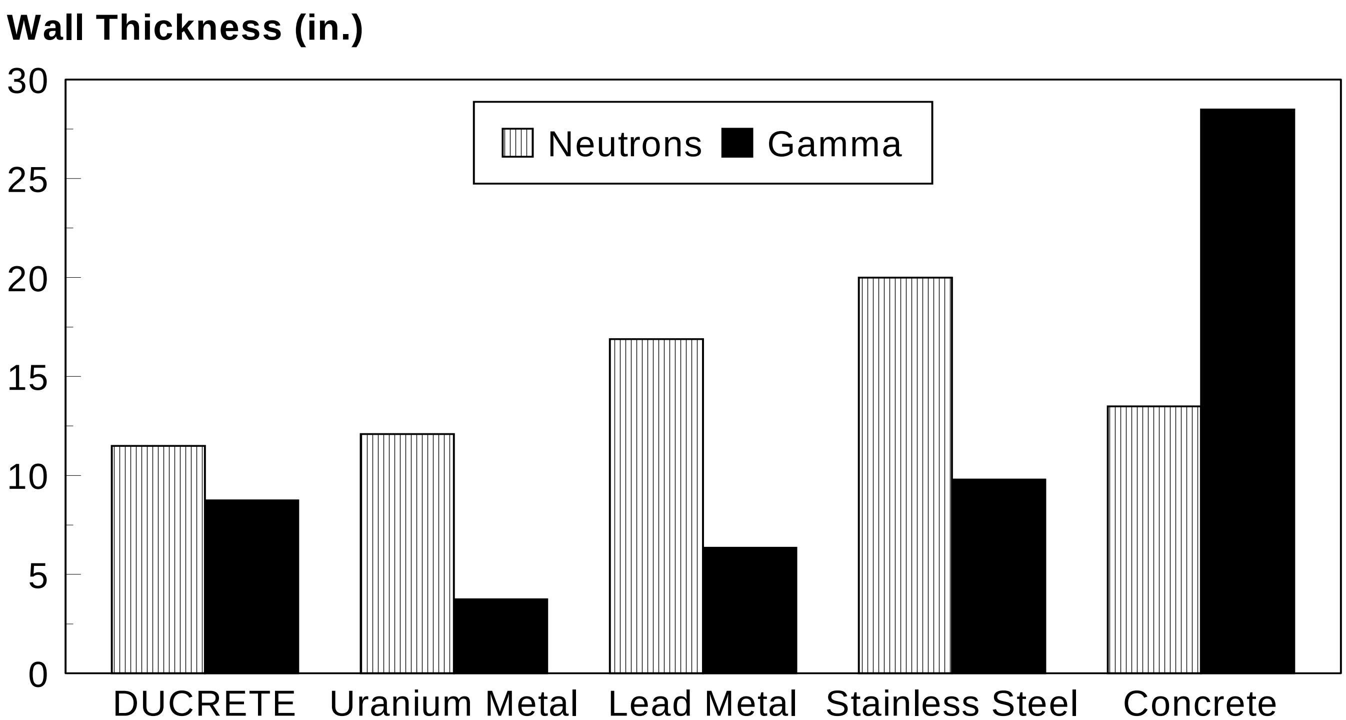
Use of DU Offers Advantages in SNF Storage, Transport, and Disposal Casks

- Concrete with DU (DUCRETE™) can be used in current cask designs, such as the concrete storage (CONSTOR) cask that is to be used for RBMK fuels
- Cermets can also be used in DU-steel modification to baskets
  - Addition of neutron absorbers
  - Addition of DUO_2 basket fill

Composition of DUCRETE™ – Depleted Uranium conCRETE

- Coarse-graded sintered UO_2 aggregates at a density of >8.9 g/cm^3
- Cementitious binder, similar to Portland cement
- Fine aggregates, like quartz, fly ash, microreinforcement, and/or colemanite sands
- Water

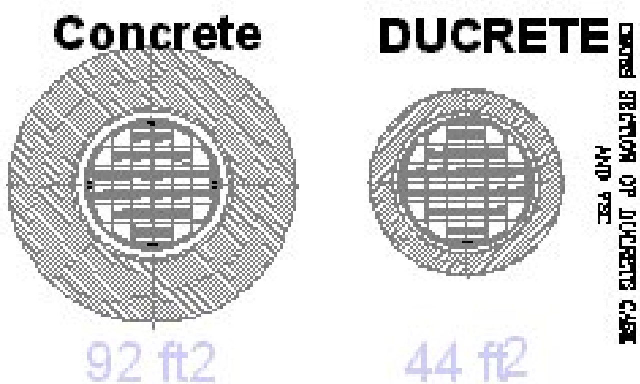
DUCRETE™ Combines the High Density of DU with Binders of Low-Z Elements to Optimize Gamma and Neutron Attenuation



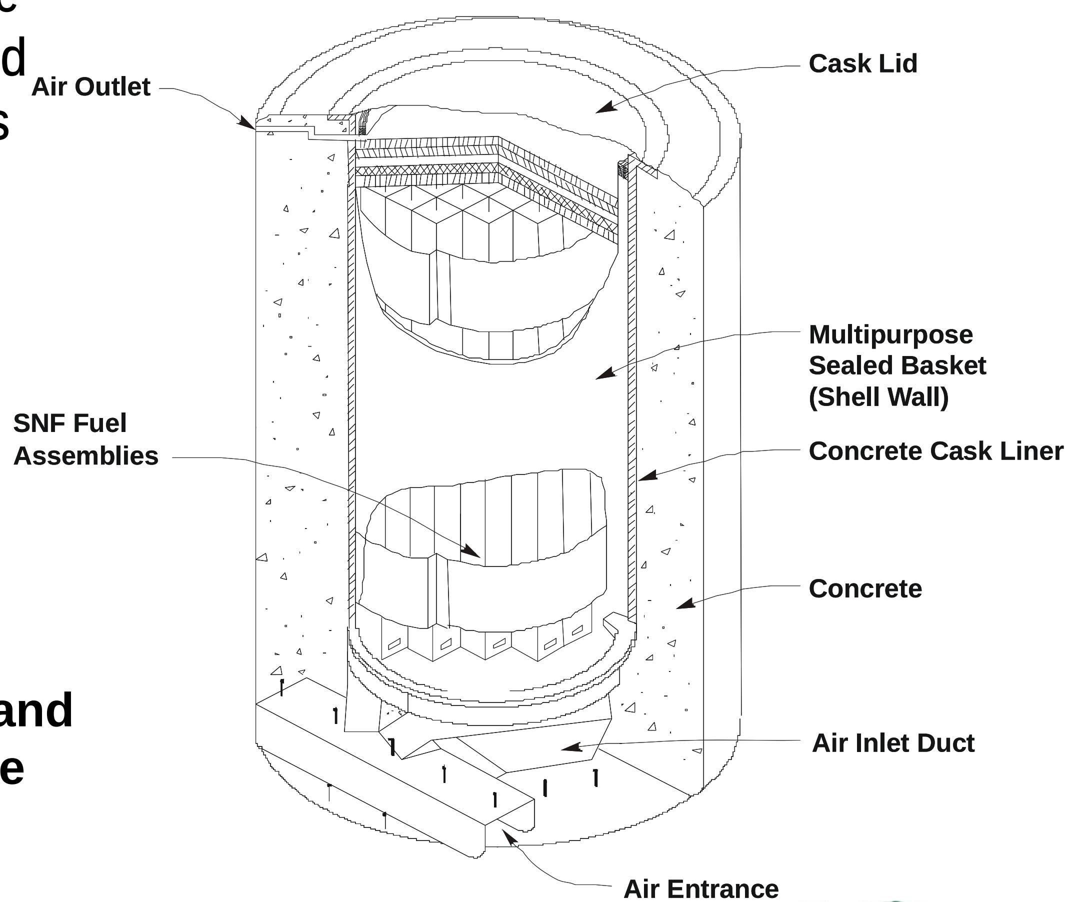
Comparison of wall thicknesses required to attenuate to 10 mR/H the neutron and gamma doses from 24 pressurized-water-reactor spent fuel assemblies

DUCRETE™ Storage Casks are Considerably Smaller and Lighter than Casks Constructed of Ordinary Concrete

For equivalent shielding capability, the DUCRETE™ cask is 35 tons lighter and 100 cm smaller in diameter than casks made from ordinary concrete



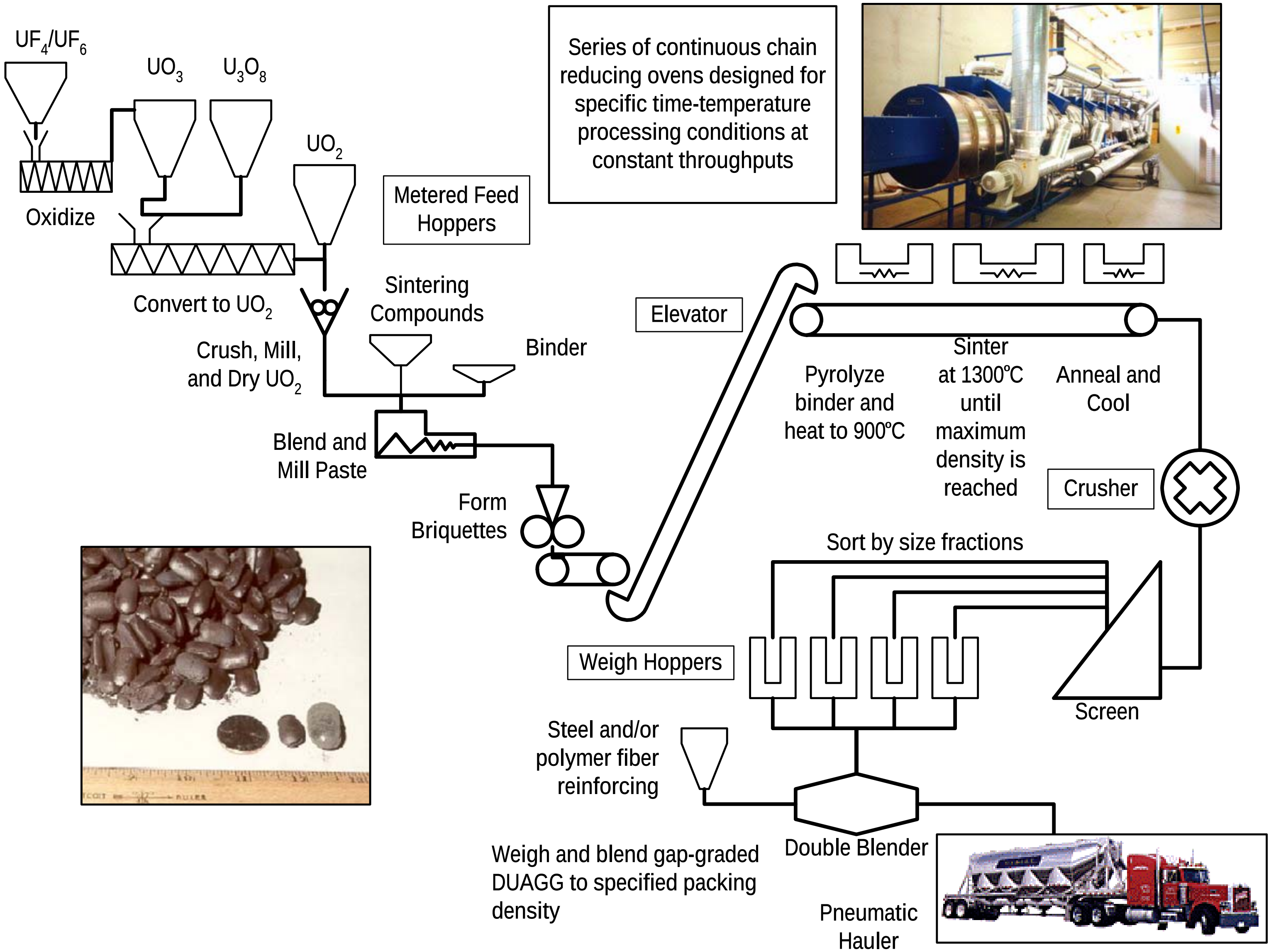
Comparison of conventional Sierra and DUCRETE™ spent fuel dry-storage casks/silos



DUAGG™ Briquettes are Stabilized DU Aggregates with Basalt Sintering Agent

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

DUAGG™ Processing and Sizing



Substituting DUCRETE™ in CONSTOR Cask Increases Capacity and Protection

- Reduces size and weight
- Allows higher thermal loads
- Meets criteria for improved technical and economic performance
- Allows enhanced physical protection within current weight limits
- Complies with emerging regulatory requirements and standards

DUCRETE™ Reduces CONSTOR Shielding to 11.5 in. and Increases Thermal Capacity by 1.5

	Sierra System		DUCRETE System			GNB CONSTOR		
Cask Dimensions	**Inside Steel Shell**	**Concrete**	**Inside Steel Shell**	**DUCRETE**	**Outside Steel Shell**	**Inside Steel Shell**	**Heavy Concrete**	**Outside Steel Shell**
Thickness (in.)	1.75	29.00	1.00	**11.50**	1.00	1.57	**17.40**	1.57
ID (in.)	70.50	74.00	70.5	72.50	95.5	70.5	73.65	108.4
OD (in.)	74.0	132.0	72.5	95.5	97.5	73.6	108.4	111.6
Inside Length (ft)	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Wall cross section (ft^2)	2.8	65.2	1.6	21.1	2.1	2.5	34.6	3.8
Wall Volume (ft^3)	41.4	977.5	23.4	316.1	31.6	37.1	518.5	56.7
End Thickness (in.)	1.75	11.6	1.00	4.6	1.00	1.57	7.0	1.57
End (2) Volume (ft^3)	27.7	183.7	8.6	38.1	8.6	17.8	74.4	17.8
Total Volume (ft^3)	69.1	1161.2	32.0	354.3	40.2	55.0	592.9	74.5
Density (lb/ft^3)	491	146	491	362	491	491	207	491
Mass (lb)	33,926	169,684	15,732	128,414	19,749	26,992	122,993	36,594
Component Mass (ton)	17.0	84.8	7.9	64.2	9.9	13.5	61.5	18.3
Container Mass (ton)		102		82			93	
Container Weight Reduction				**-20%**			**-8%**	
Shielding Equivalency (lb/ft2)	**72**	**353**	**41**	**347**	**41**	**64**	**301**	**64**
Total Shielding Equivalency		**425**			**429**			**430**

Theoretical Thermal Conductivities of Composites Used in Calculations

Concrete	Volume Percent of Component					Thermal Conductivity, W/(m•K)
	Cement Paste	Steel	Lime-stone	Barium Sulfate	UO_2 Powder	
Normal Concrete	0.25	0.10	0.65			2.9
Heavy Concrete	0.25	0.10		0.65		3.4
DUCRETE	0.25	0.12			0.63	7.0

Several DUCRETE™ Demonstration Programs Have Been Successfully Completed

Test block sectioned after curing

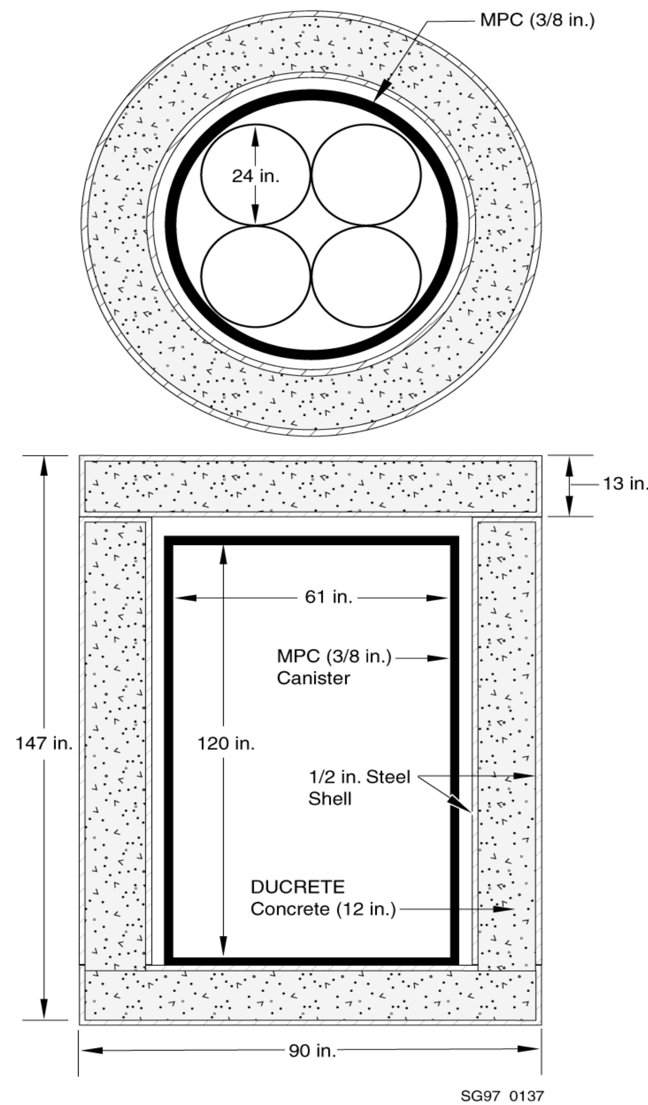
30-gal-drum overpack

Conceptual Designs of DUCRETE™ Casks Have Been Developed by Duke Power for HLW Storage

Shielding Effectiveness vs Wall Thickness

DUCRETE™ Thickness (in.)	Surface Dose Rate (mrem/h)	Dose Rate @ 2 (mrem/h)
10	41	10
11	27	6
12	19	4
13	15	3
14	12	2
15	9	2
16	8	1

DUCRETE Overpack System



Current DUCRETE™ Technology Development

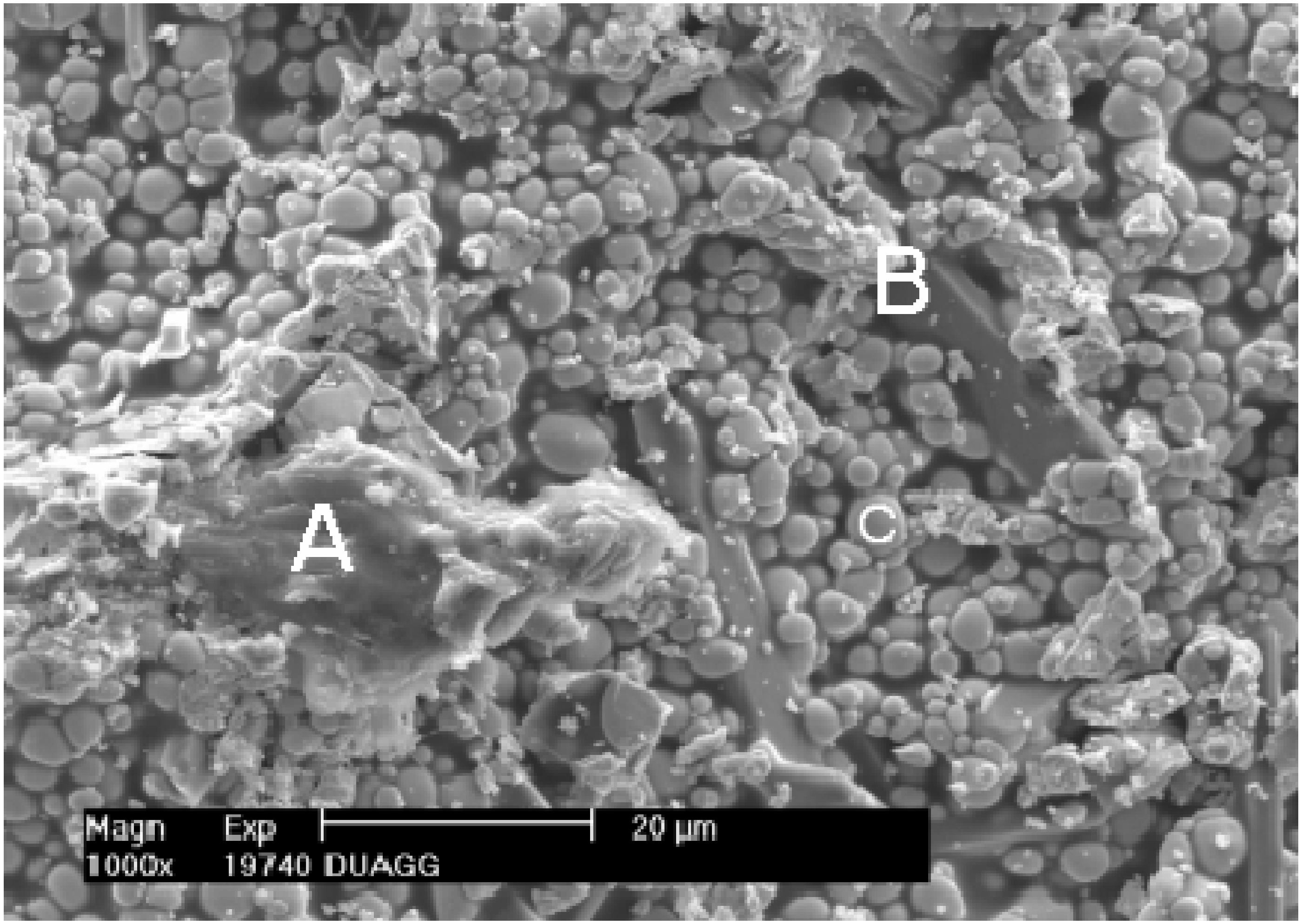
- DUAGG™ manufacturing process optimization, cost reduction, and demonstration
- Material properties characterization for matrix and aggregate stability with aging under service conditions
- Optimized binder and DUAGG™ for gamma and neutrons for specific cask designs
- Fabrication and testing of full-scale cask prototypes under a cooperative research and development agreement (CRADA)

Current Laboratory Studies

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

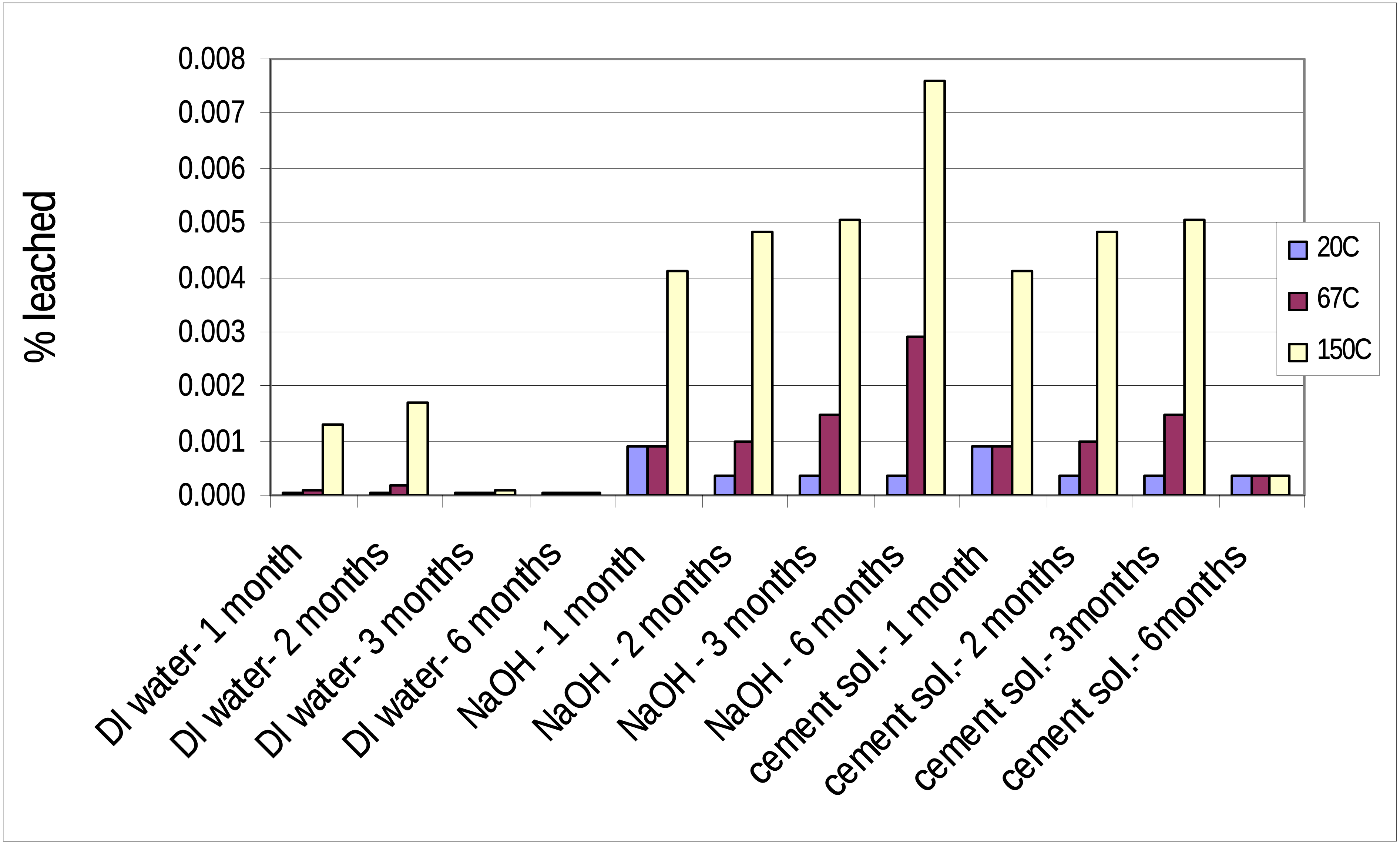
- At a constant surface-to-liquid ratio of 1:10, the sintered DUAGG™ samples are exposed to
  - distilled (DI) water
  - 1 *N* sodium hydroxide (NaOH) standard solution
  - saturated water extract of high-alkali cement
- The three exposure temperatures and six time intervals are 25, 66, and 150ºC at intervals of 30, 60, 90, 180, 240, and 360 days

Unexposed DUAGG™

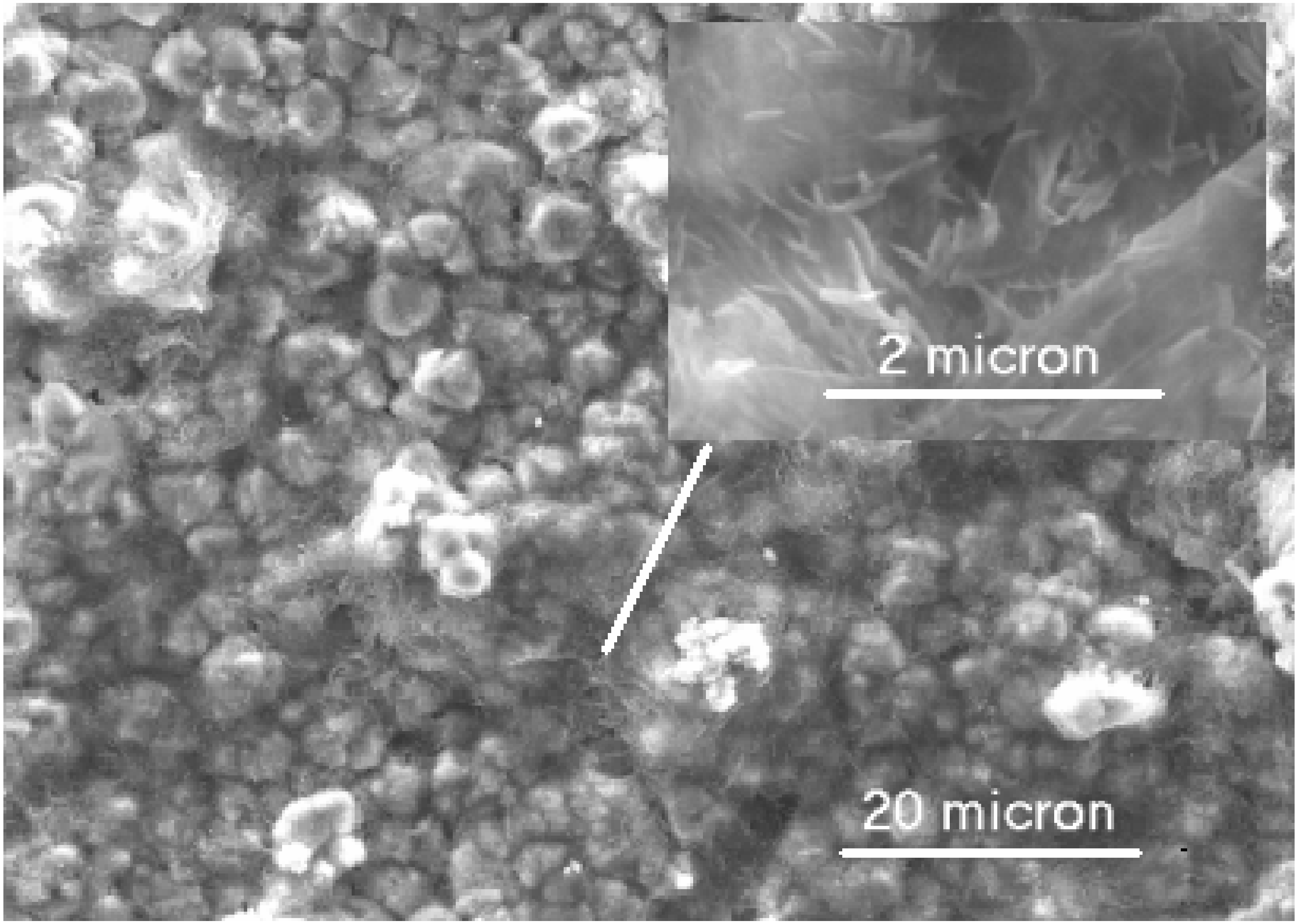


Particle A contains Al
Particle B contains Ti and some Mg
Area C contains the round DU particles surrounded by the basalt phase

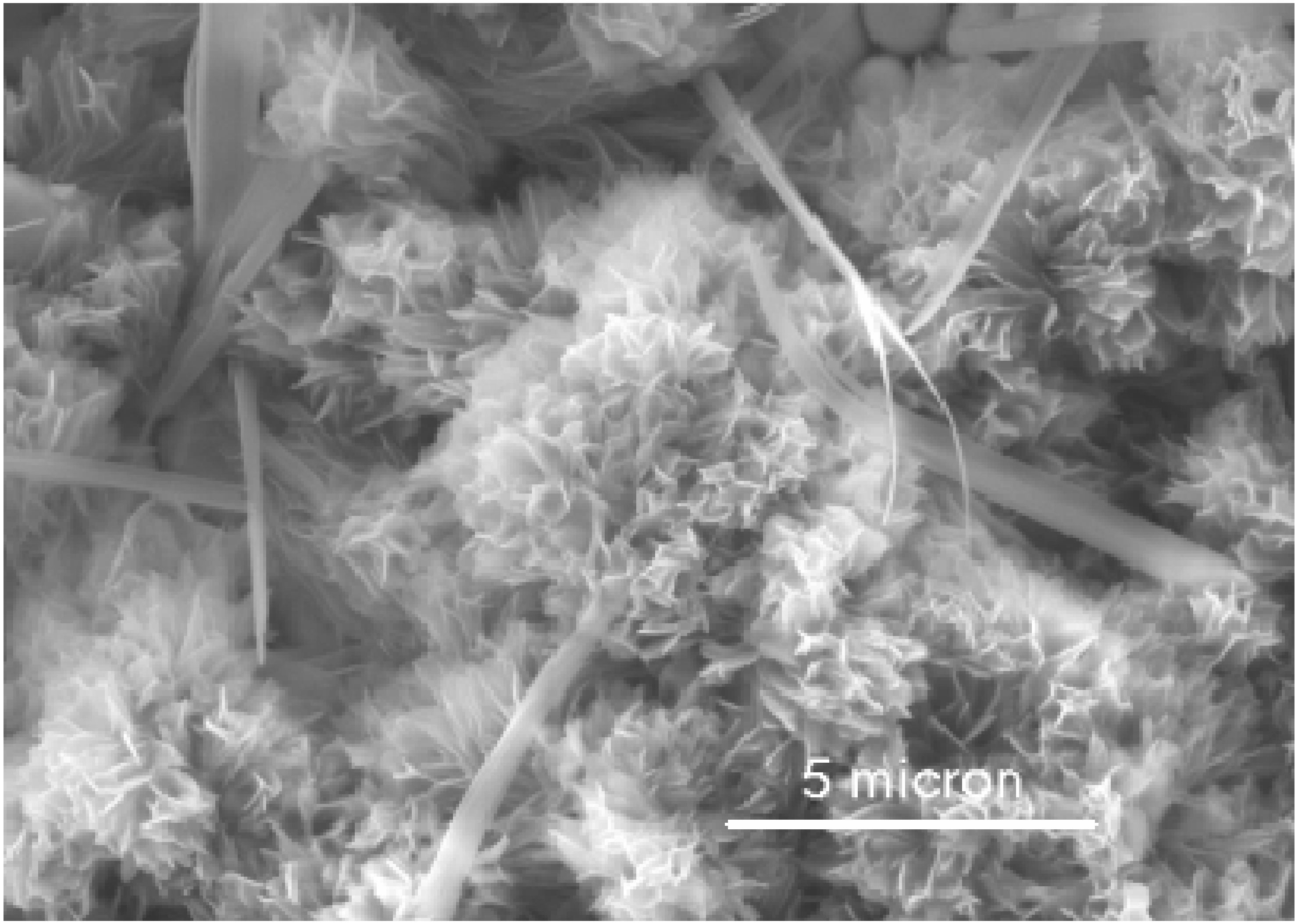
Uranium Leached from DUAGG™



DUAGG™ Exposed to Cement Water for 6 Months at 150˚C



DUAGG Exposed to 1 *N* NaOH for 6 months at 150˚C



Alkali reaction products with Na, Al, Si, Ca, and Ti

Proposed CRADA Between ORNL and the U.S. GNSI for the Development of Advanced Spent Nuclear Fuel Storage, Transport, and Disposal Casks and Overpacks

CRADA = Cooperative Research and Development Agreement; GNSI = General Nuclear Services, Inc.

Conclusions

- Combinations of gamma-absorbing DU and neutron-absorbing hydrated binders are shown to effectively reduce the size and weight of storage, transport, and disposal casks

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Additional Material for Discussion

Summary

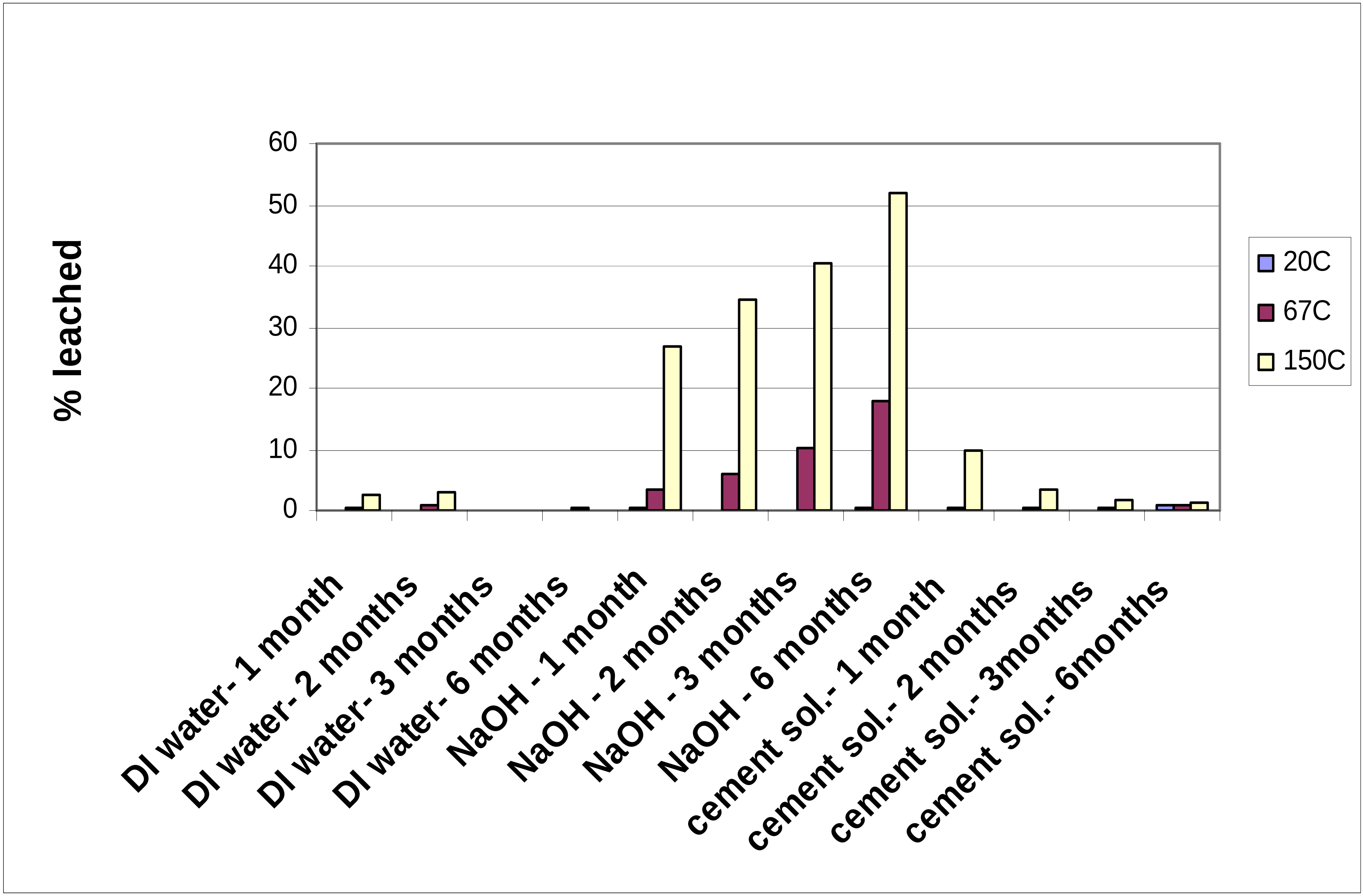
- DUCRETE™ casks have
  - Smaller dimensions
  - Lighter weight
  - Higher SNF heat loading
  - Potentially greater physical protection against assault
- We are conducting laboratory experiments to characterize DUAGG™/DUCRETE™ materials
- We are conducting preliminary cost studies
- We are pursuing a collaboration with GNSI to design and demonstrate the next generation of SNF casks

Thermal Conductivities of DUCRETE™ Components Used in Calculations

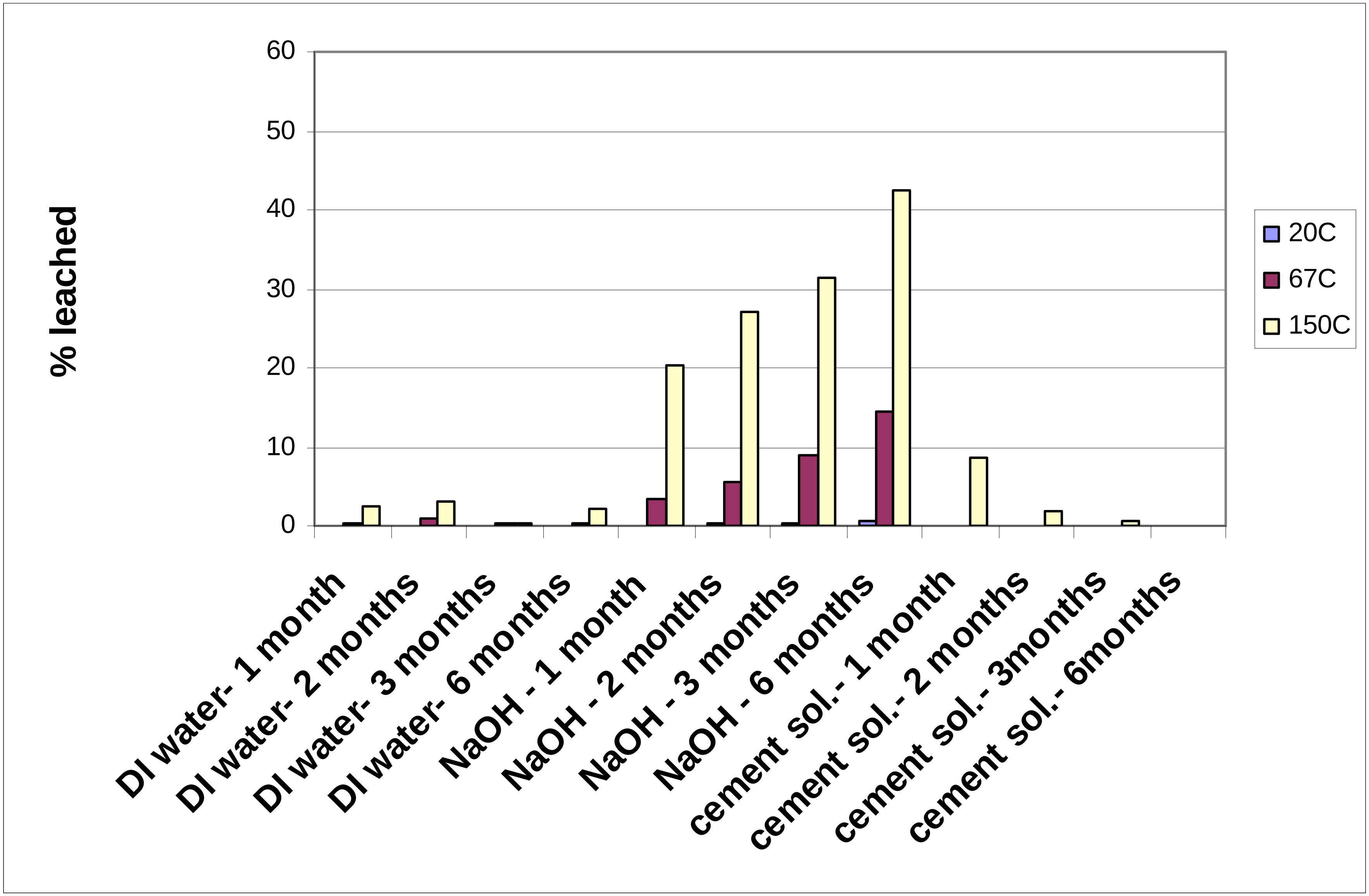
Material	Thermal Conductivity, W/(m•K)
Iron	84.3
Stainless Steel	16.0*
Cement Paste	2.96*
Limestone	0.94*
Barium Sulfate	2.51*
UO_2 (Solid)	8.37
UO_2 (Powder, 68 vol %)	6.93*

Used in subsequent calculations

Aluminum Leached from DUAGG™



Silicon Leached from DUAGG™



GNB CONSTOR Cask for RMBK SNF

Estimated Need for DUO_2

Purpose	Amount, tonnes	Time, years
Lab scale tests	2–5	Now
Intermediate-scale tests	5–10	1–2
Pilot-scale cask fabrication	18–22	2–3
Full-scale cask fabrication	210–240	3–5
Total	380–440	7–11

Potential costs (current commercial) $1.5M–$30M

Preliminary Plant Design Study for the Production of DUAGG™

Objective and Scope

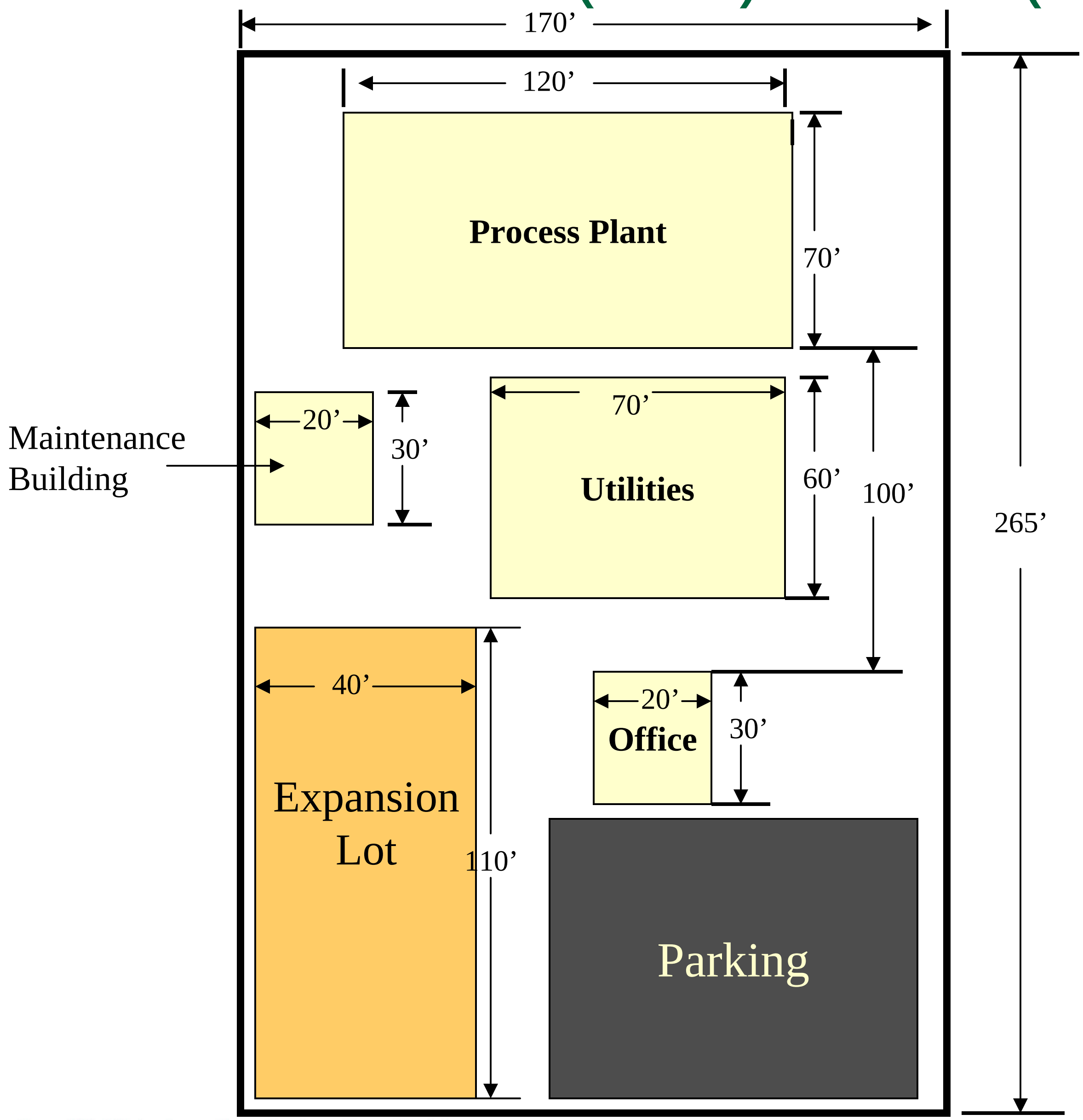
- Conceptual design for DUAGG™ plant to estimate potential capital and operating costs

- Design of a DUAGG™ plant that receives DUO_2; presses and sintered briquettes; and crushes, sizes, and packages DUAGG™ to be used in high-strength DUCRETE™ for SNF casks

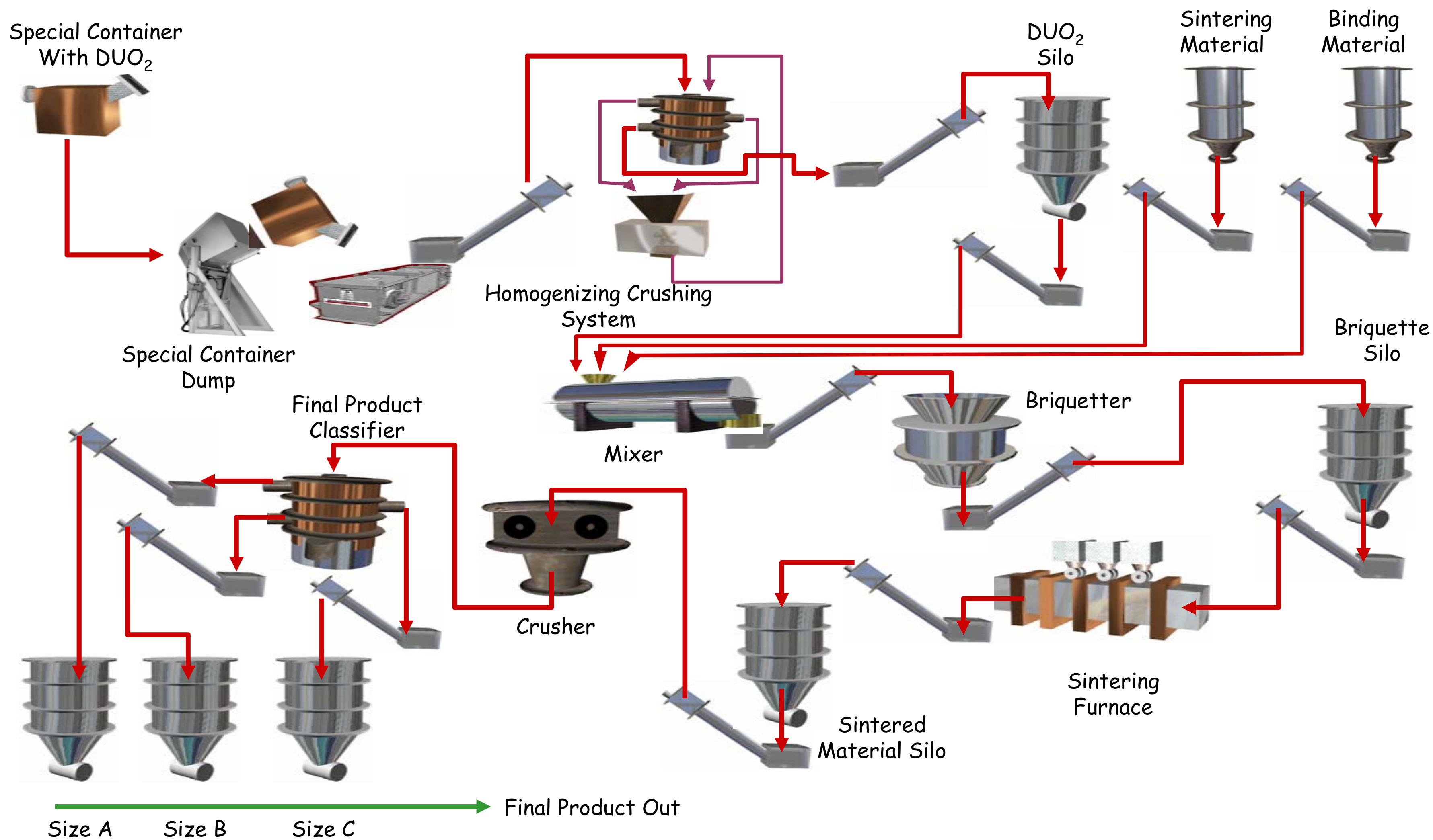
Baseline Assumptions for Scaling the Plant and Equipment

- Achieve production rate of 2834 tonnes per year to meet 30% penetration of domestic market for SNF storage and transport casks (about 50 casks)
- Receive DUO_2 from external source
- Receive sintering and binding materials for milling, blending, pressing, sintering, and crushing
- Produce crushed, gap-graded, and amended DUAGG™ product for use in DUCRETE™ that is formed off-site

Site Area: 170 ft (52 m) x 265 ft (81 m)



Process Unit Operations



Preliminary Capital Cost Elements

	Capital Costs ($1,000 USD)
Civil/Site Preparation	**500**
Utilities Building Services	**56**
Building Structures	**2,620**
Process Equipment	**2,224**
Special Process Services	**35**
Engineering	**1,591**
Piping	**1,204**

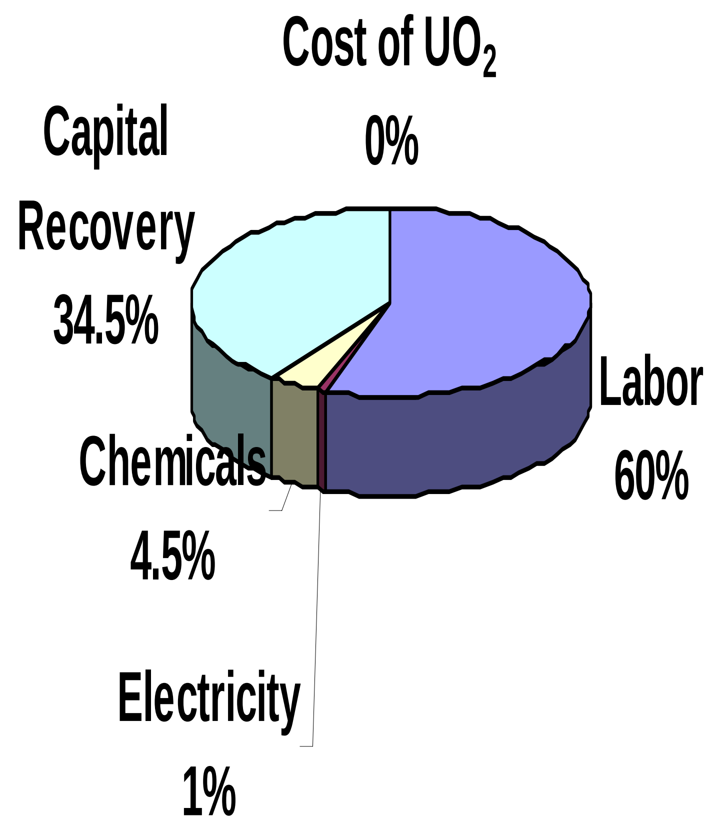
Preliminary Capital Cost Elements (cont.)

	Capital Costs ($1,000 USD)
Installation Labor	**1,205**
Electrical	**220**
Spare Parts	**346**
Management	**1,000**
Safety Systems	**600**
Shipping	**110**
Total Capital Investment	**11,601**

Preliminary Total Operating Cost

Baseline Cost of DUO_2: $0 USD/ton

	$1,000 USD/year
Labor	**4,014**
Electricity	**56**
Chemicals	**309**
Cost of DUO_2	**0**
Capital Recovery	**2,320**
Total Operating Cost	**6,699**



Future Engineering Analyses

- Determine the specification of DUO_2 feed to plant
- Simplify the grinding, mixing, and sintering processes to reduce labor required
- Optimize briquetting and final grinding processes
- Examine other agglomeration processes
- Conduct a parametric process parameters study on the reproducibility of DUAGG™
- Research microreinforcement in the DUCRETE™

Russian RBMK Spent Fuel Cask with Heavy Concrete

GNB CONSTOR test cask for RBMK SNF

Heavy concrete with steel shot and barium sulfate