Used Fuel Disposition Campaign

DBFT Engineering Overview

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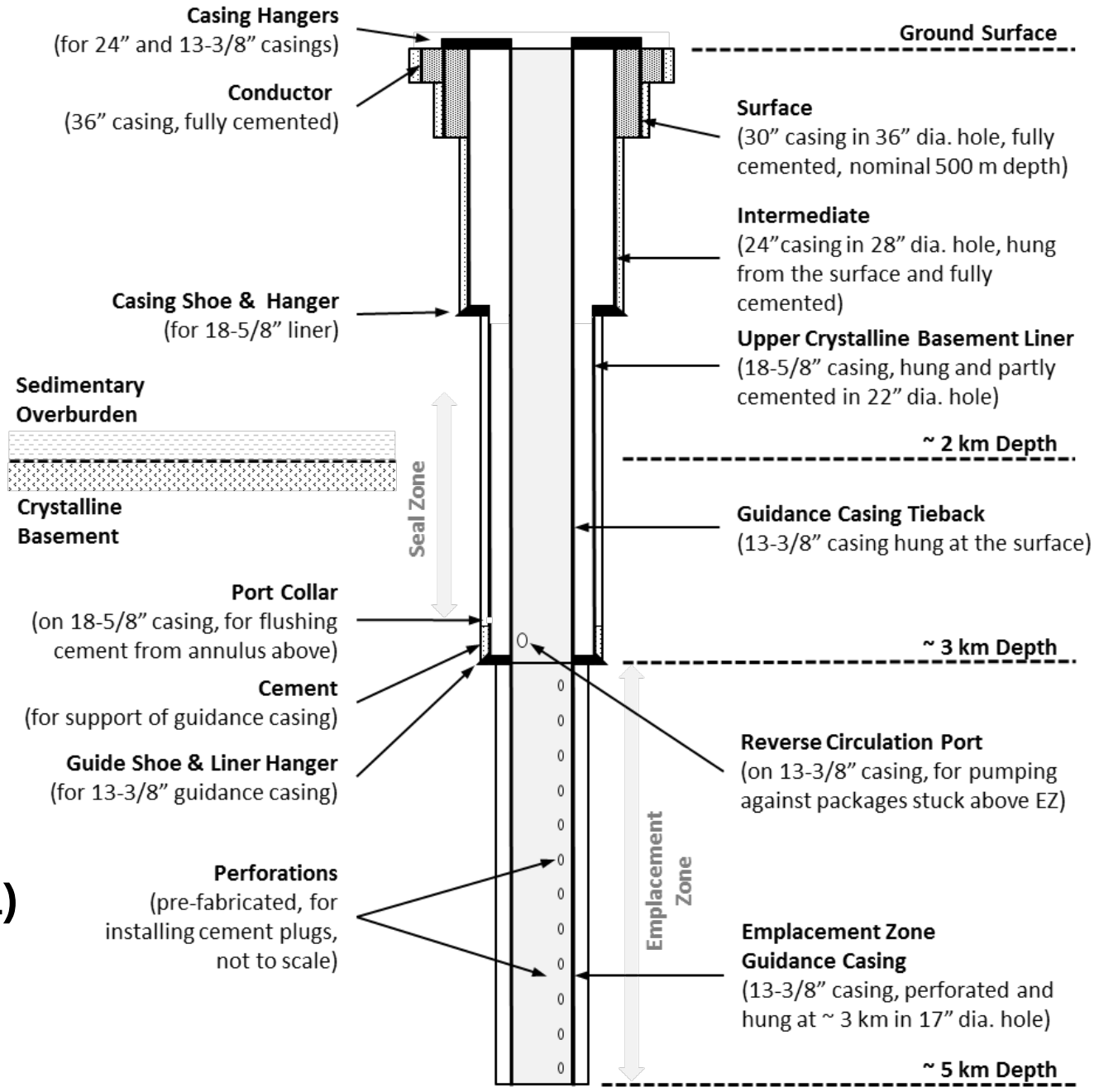
DBFT Engineering Overview: Outline

- Field Test Borehole
- Emplacement Method Selection for Field Test
- Waste Packaging Concepts
- Dropped Package Fragility Analysis
- Thermal and Thermal-Hydrologic Analysis
- Impact Limiters
- Electromechanical Package Release
- Terminal Sinking Velocity Analysis
- Surface Handling/Transfer Concept

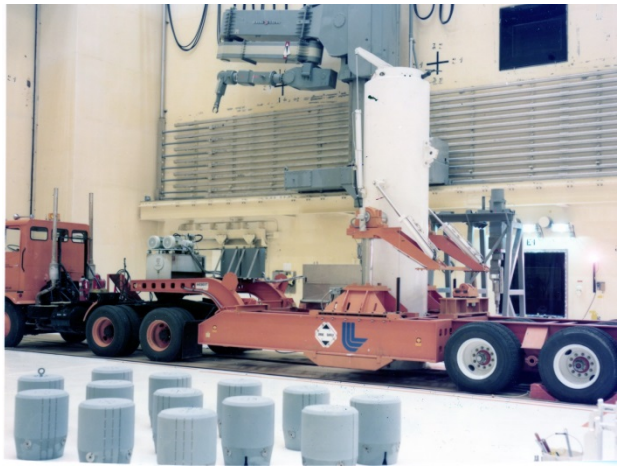
No radioactive waste materials will be used in the Deep Borehole Field Test.

Field Test Borehole

- **17” Dia. @ 16,400 ft.**
- **13-3/8” Guidance Casing to TD**
- **22” Dia. Sealing Zone**
- **Modeled After Reference Disposal Concept (Arnold et al. 2011)**



Spent Fuel Test–Climax: Nevada Test Site 1978-83
Eleven Irradiated PWR Assemblies Stored 3 yr





DBFT Engineering Overview: Compare Emplacement Methods

	Meets Security	Multi-Package Emplacement	Emplacement Cost	Comments
Free Drop	No		$	• Status uncertain during descent
Electric Wireline	Yes		$$	• Impact limiter on every package
Coiled Tubing	Yes	✓	$$$	• Limited tubing life (much less than needed to load a borehole) • (Unless packages are threaded together in strings → basement) • Don't force packages downhole
Drill-String	Yes	✓	$$$$	• Heavy strings • Packages threaded together • Complex basement
Conveyance Casing/Drill-String	Yes	✓	$$$$	• Packages stacked in conveyance casing at the surface, then lowered • Heavy strings • Packages smaller/borehole larger
✓ = Requires a "basement" facility for assembling package strings				

DBFT Engineering Overview: Emplacement Method Cost-Risk Analysis

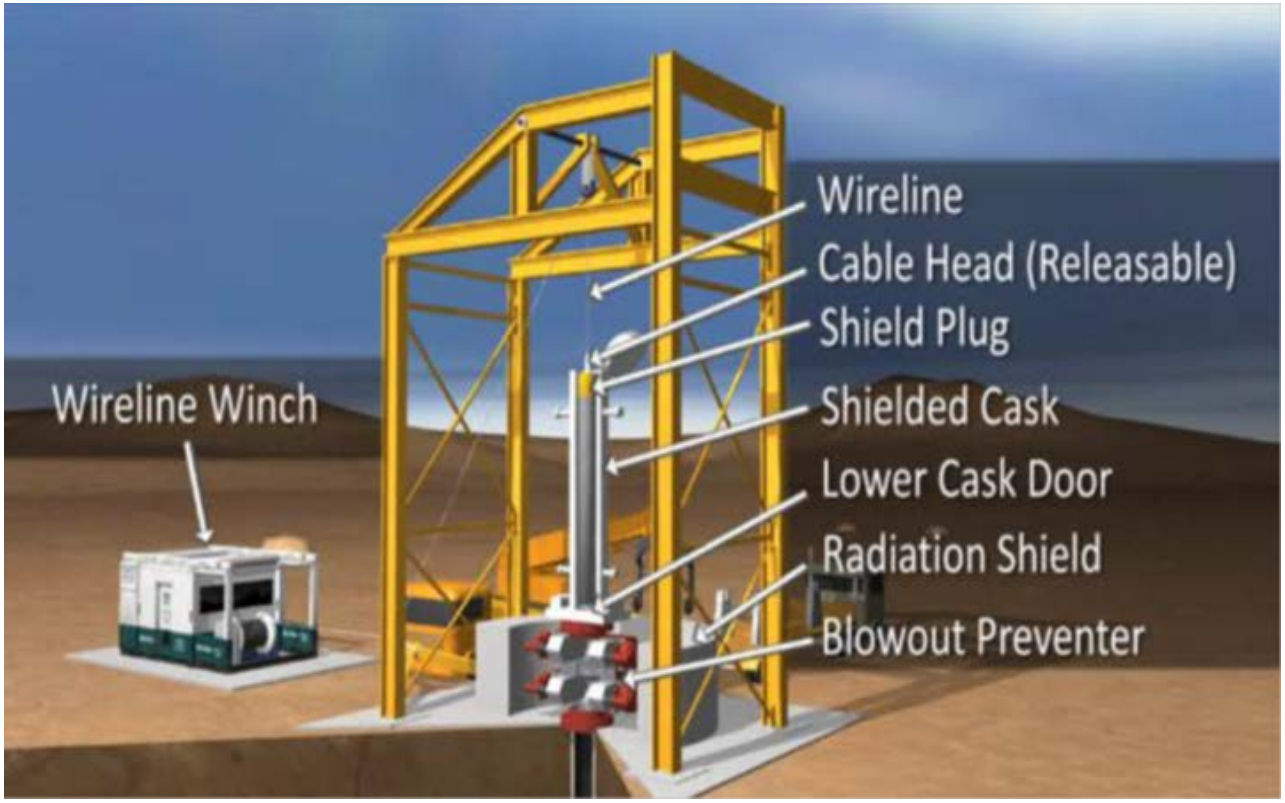
- **Results Summary**
- **Drill-String Operations Would Be ~52× More Likely to Cause a Radiological Release**
  - Prototype borehole, 400 packages total
  - Assemble and emplace strings of 40 packages

	Initial Results	
	Wireline	**Drill-String**
Probability of incident-free emplacement of 400 WPs	**97.83%**	**99.24%**
Approximate total costs if successful ($ million)	**23.5**	**41.9**
Expected performance against the defined performance metrics		
Expected value of costs ($ million) for outcomes weighted by probabilities, considering both normal and off-normal events	23.7	43.9
Expected total time of operations (days) for outcomes weighted by probabilities, considering both normal and off-normal events	430	434
Aggregated probability of radiation release	1.35E-04	7.08E-03

SNL 2016. *Deep Borehole Field Test: Conceptual Design Report.* FCRD-UFD-2016-000070. June 30, 2016.

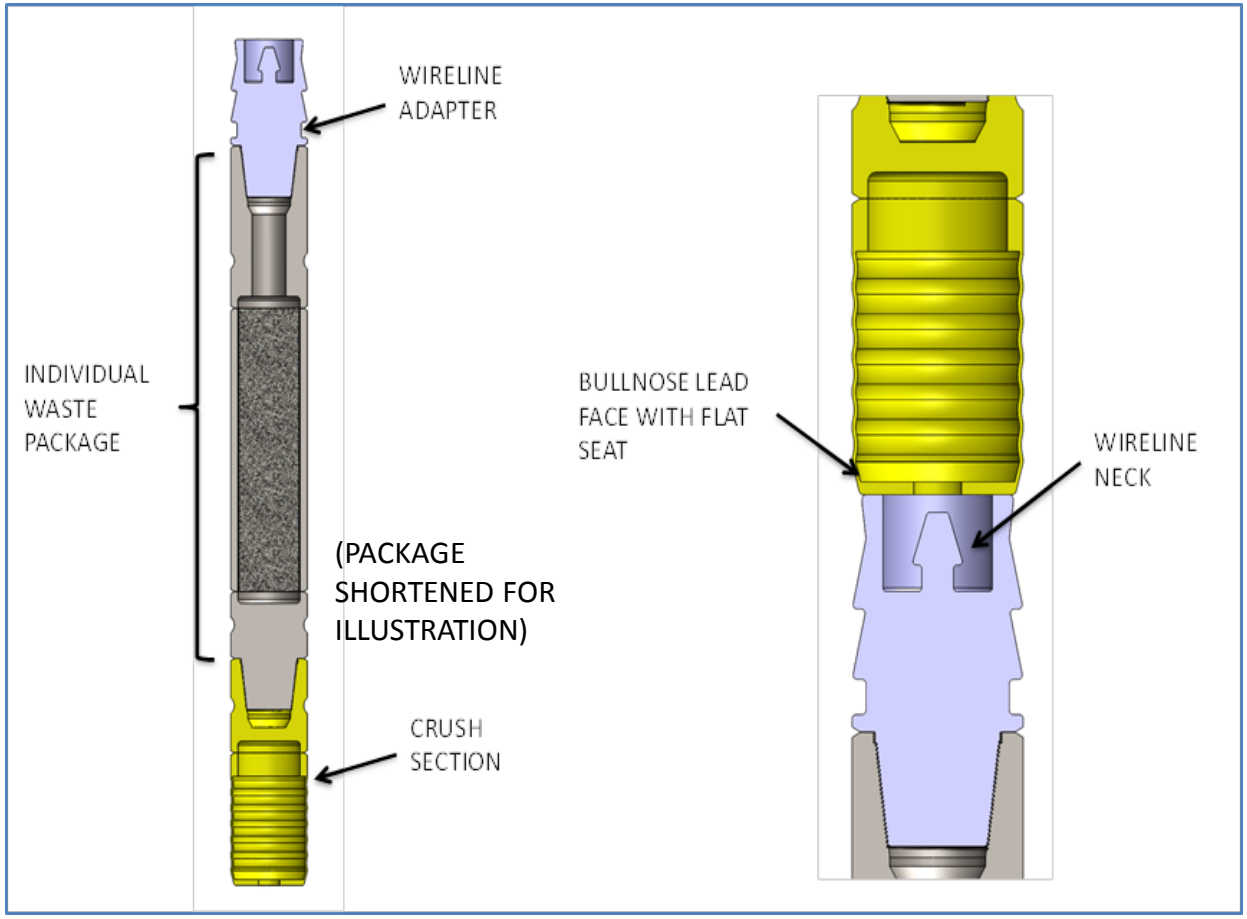
DBFT Engineering Overview: Wireline Emplacement Concept

- **Modern Electric Wireline**
  - Tuffline® or equiv.
  - 12,000 lb without capstan
  - No “seasoning”
- **Electromechanical Release**
- **Shielded “Pit”**
- **Headframe**



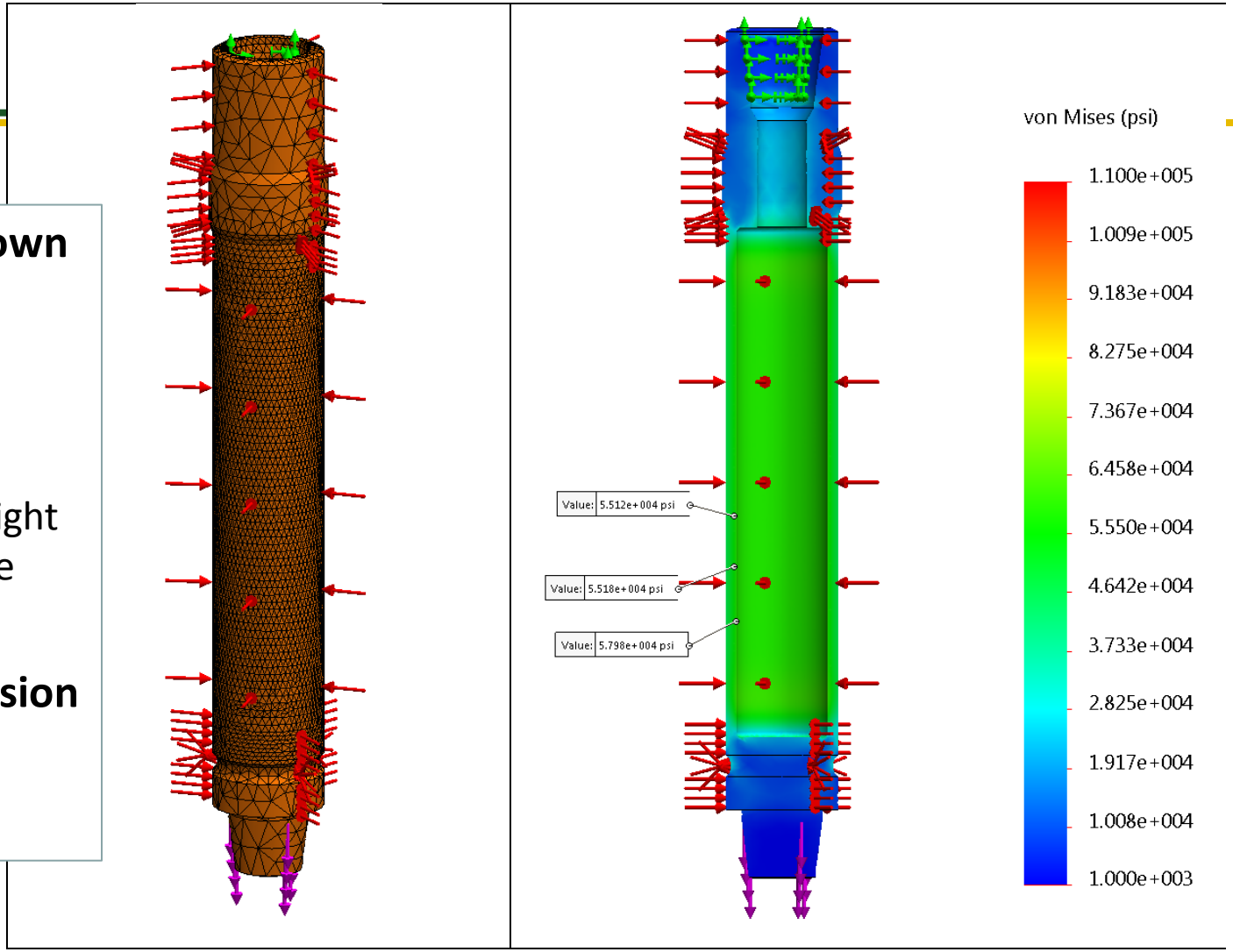
DBFT Engineering Overview: Packaging for Wireline Emplacement

- **Flask-Type Shown**
- **Attachments**
  - Wireline latch and fishing neck (upper)
  - Impact limiter (lower)
- **End Plugs Welded and Heat-Treated**
- **Tapered Fill Plug**
- **API NC-77 Threads Provide Containment Backup**



Package Stress Analysis

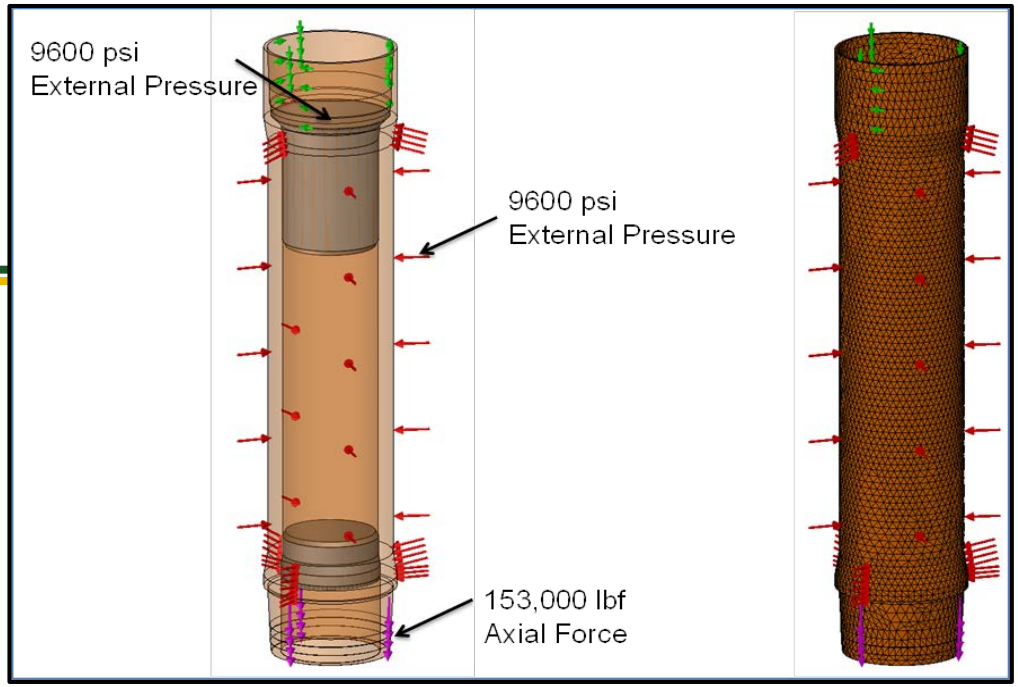
- **Flask-Type Shown**
- **Analyze for**
  - 9,560 psi fluid pressure
  - 154,000 lb weight of 40 reference packages
- **Axial Compression *Decreases* von Mises Stress**

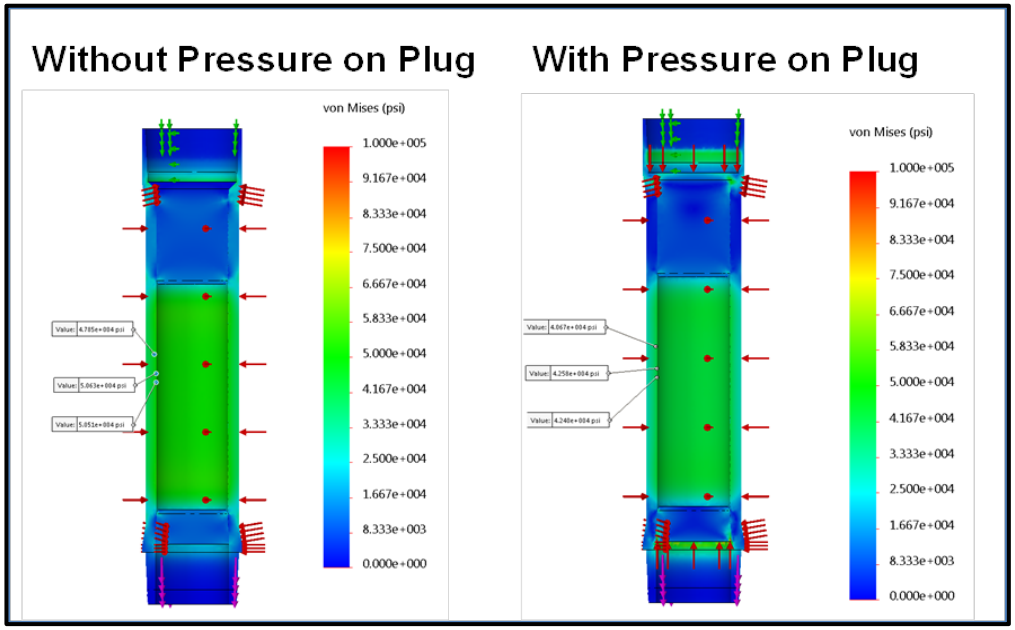


Numerical factor of safety: 2.1 for 110 ksi material

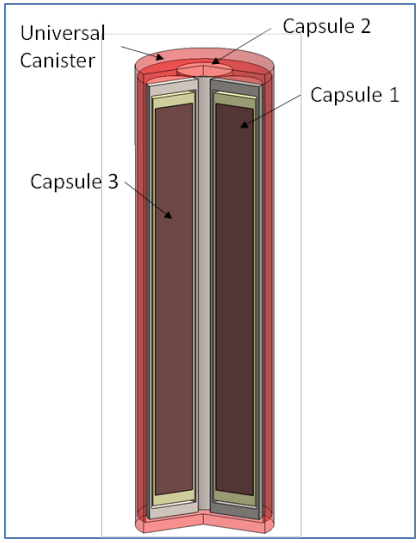
Internal Semi-Flush Disposal Overpack

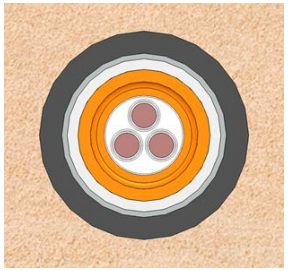
- Tapered Fill Plug (upper shield plug) with Metal-Metal Seal
- Welded & Heat-Treated Lower Plug
- Mating Box & Pin Threads on Attachments
- Take Credit for Casing Threads as Pressure Backup
- Thread Leakage *Decreases* von Mises Stress on Fill Plug



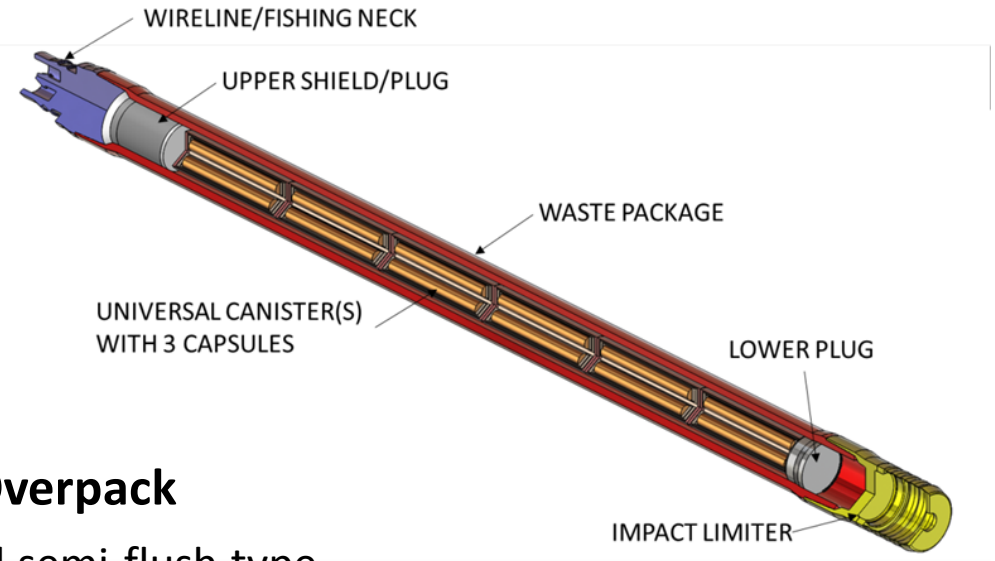


Overpack Concept for Pre-Canistered Cs/Sr Capsules





Cs/Sr capsule 3-packs, canistered



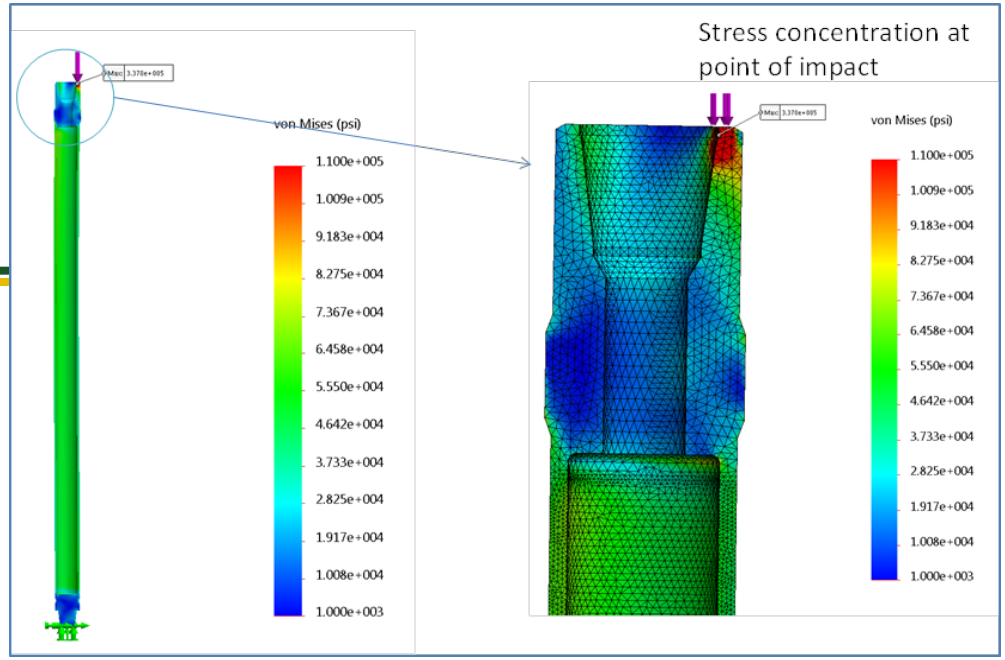
- **Disposal Overpack**
  - Internal semi-flush type
  - Holds 18 capsules (fits NAC LWT cask)
  - Internal semi-flush type, medium size
  - Max. OD 9.044”, min. ID 6.671”
  - P110 medium-carbon steel
  - Tube wall thickness 0.93”
  - Overpack wall temperature limit 250°C

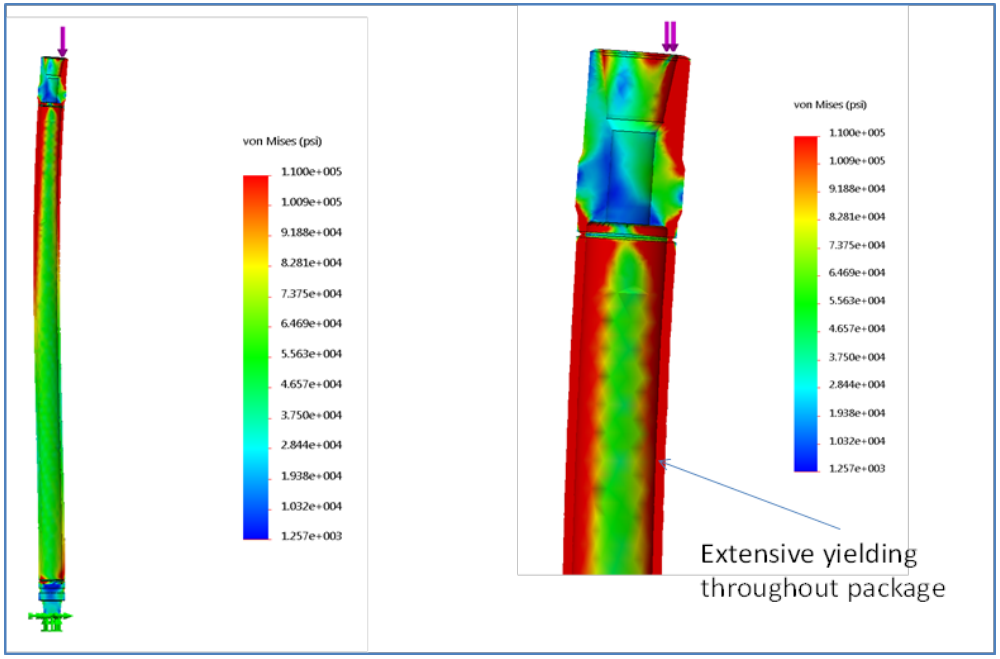
Quasi-Static Fragility Analysis for Dropped Packages

One package dropped at 2.5 m/sec

- **Quasi-Static Stress Analysis**
- **Impulsive Force Concentrated Over 40° of Perimeter**
- **Strings of 1, 5, 10 or 20 Dropped**
- **von Mises Stress (110 ksi yield)**
- **20× Horizontal Exaggeration**
- **Conclusion: Strings of >1 Package Produce Extensive Yielding**

String of **20 packages**, threaded together, and dropped at 2.5 m/sec

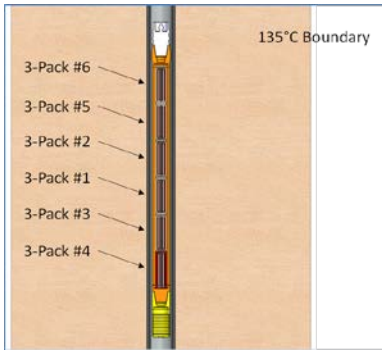


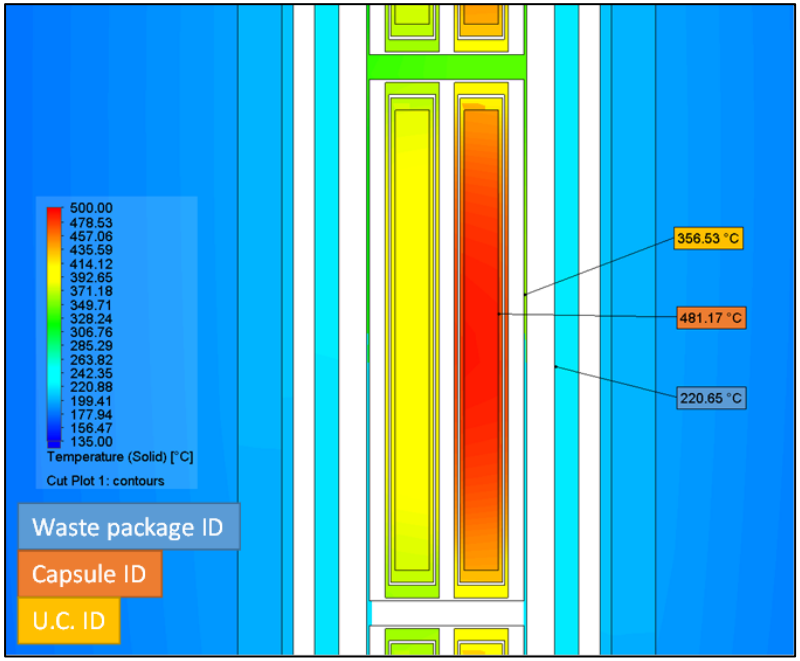


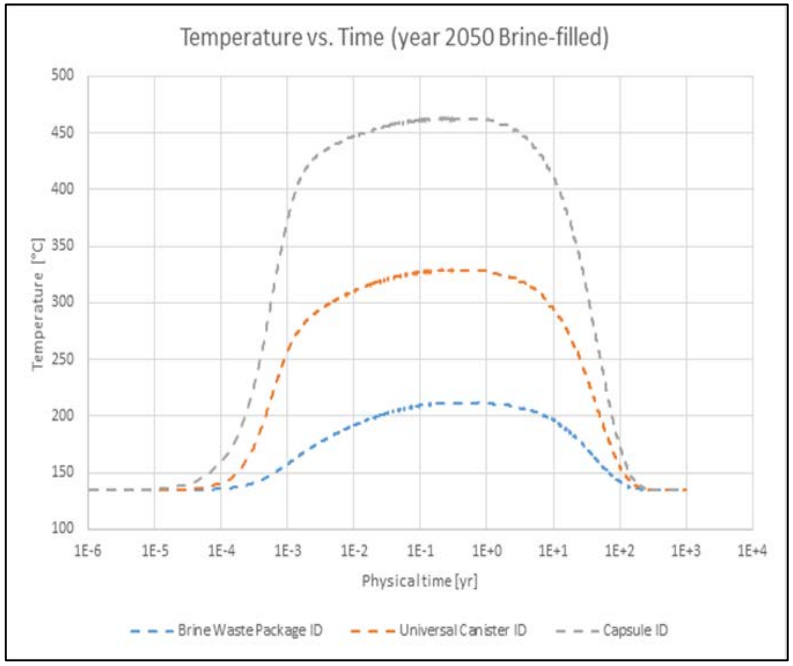
Used Fuel Disposition

DBFT Engineering Overview: Waste Package Thermal Simulation

- High-fidelity thermal simulation (SolidWorks®)
- Hottest SrF_2 capsules emplaced in 2050
- Symmetry model (top & bottom)
- Brine filled void spaces
- Peak temperature < 250˚C (inside surface of overpack)

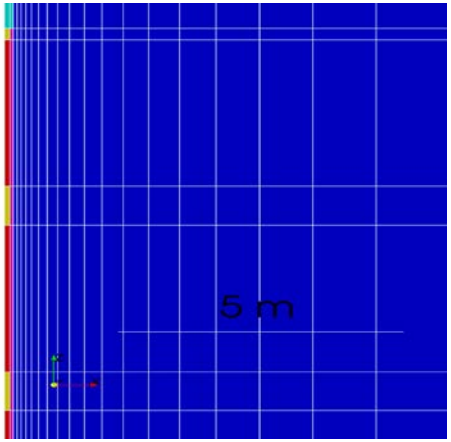


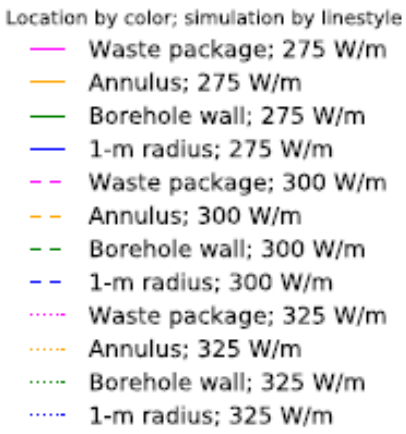


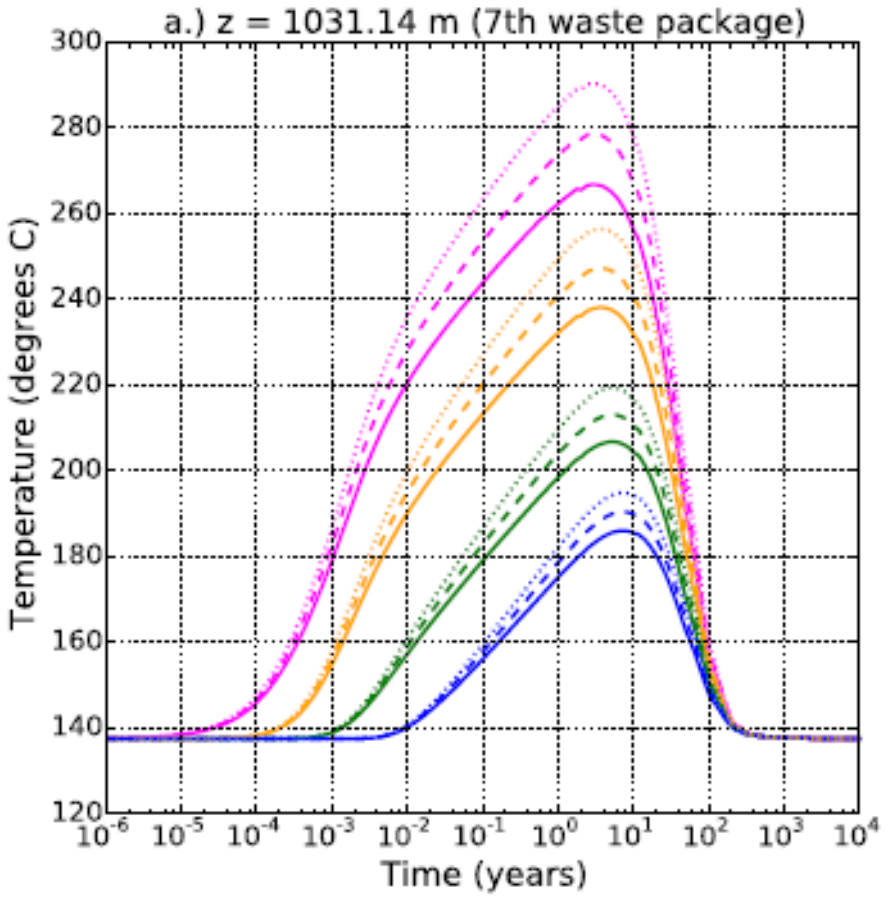


DBFT Engineering Overview: Thermal-Hydrologic Simulation

- PFLOTRAN (open-source THC HPC code)
- 1,936 capsules in 108 packages
- Geothermal gradient, fluid flow
- Axisymmetric, single-borehole model
- Disturbed rock zone
- Peak package temperature ~250˚C
- (Brine-filled borehole results shown)





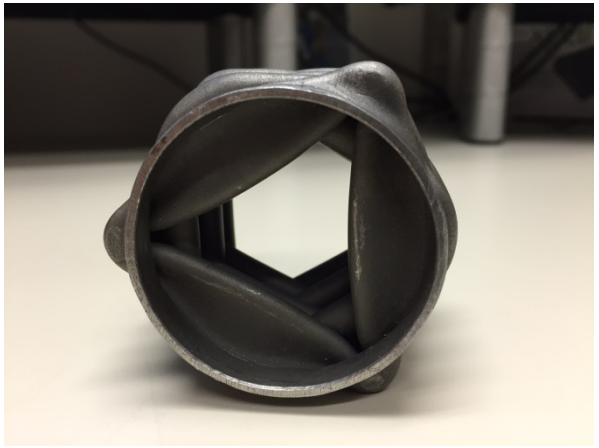


Impact Limiter Example

Hanford Multi-Canister Overpack Absorber

- Single Axis
- Compositionally Stable Downhole (all metallic)
- Operates in Fluid
- Design for Progressive Collapse
- Design for No Jam-Up





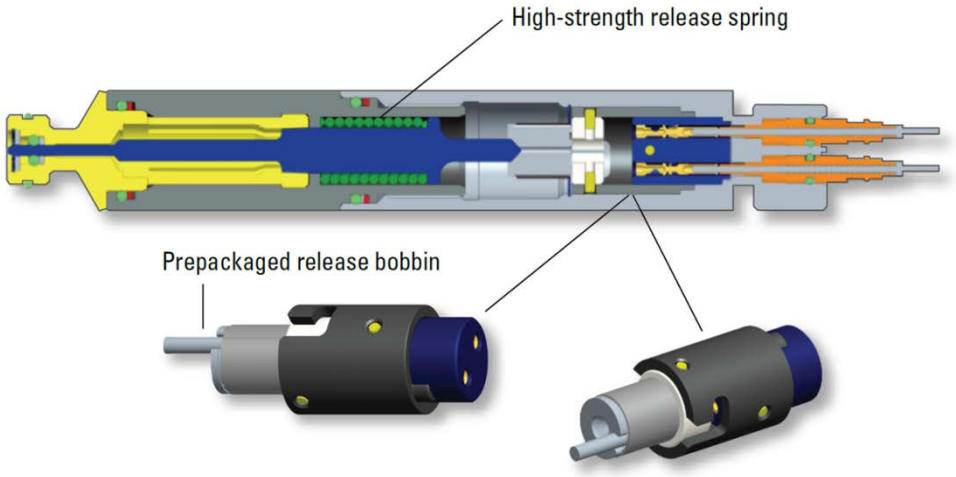
Objective: Limit deceleration of a dropped package to ~3g on impact with borehole bottom

See also:

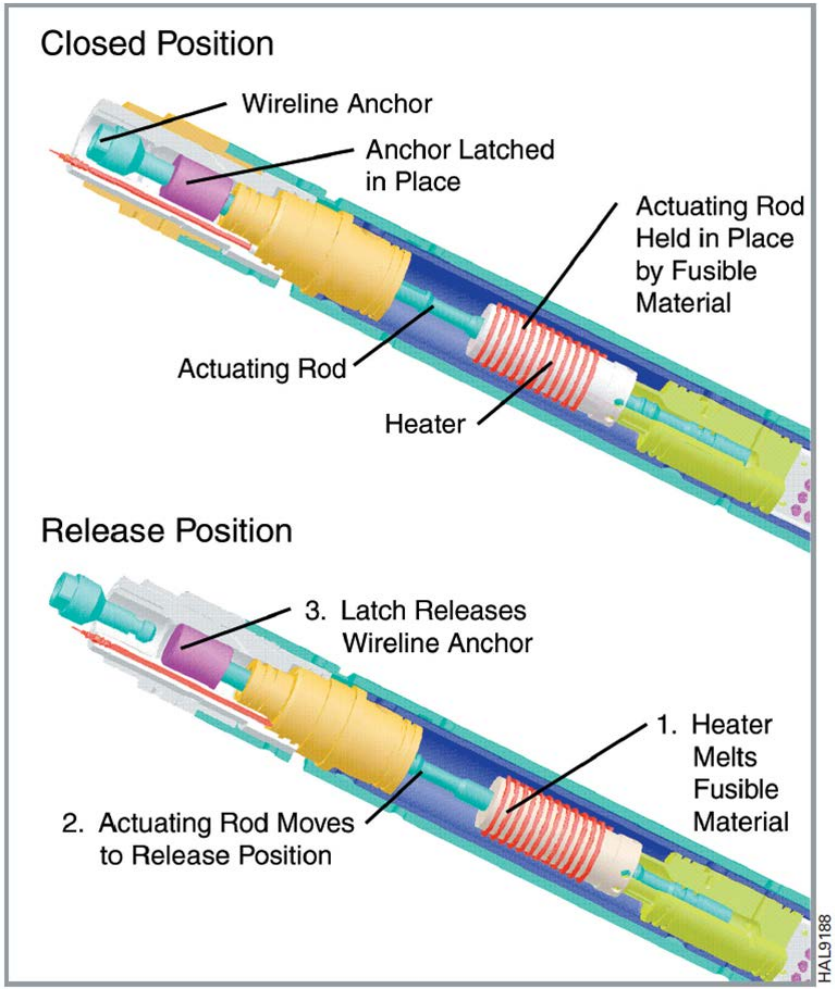
Noss, P.W., J.C. Nichols, and S.R. Streutker 2000. "MCO Impact Absorbers Using Crushable Tubes." WM 2000 Conference, Tucson, AZ.

Photos from: Brad Day, Sandia National Laboratories, Carlsbad NM.

Releaseable Wireline Cable Tools



- **SLB SureLOC 12000®**
  - Up to 12,000 lb working load
  - Temperature & pressure rated
  - Single-shot
  - Releases at up to 1,000 lb load



- **Haliburton RWCH®**
  - Load capacity > any wireline
  - Temperature & pressure rated
  - Single-shot

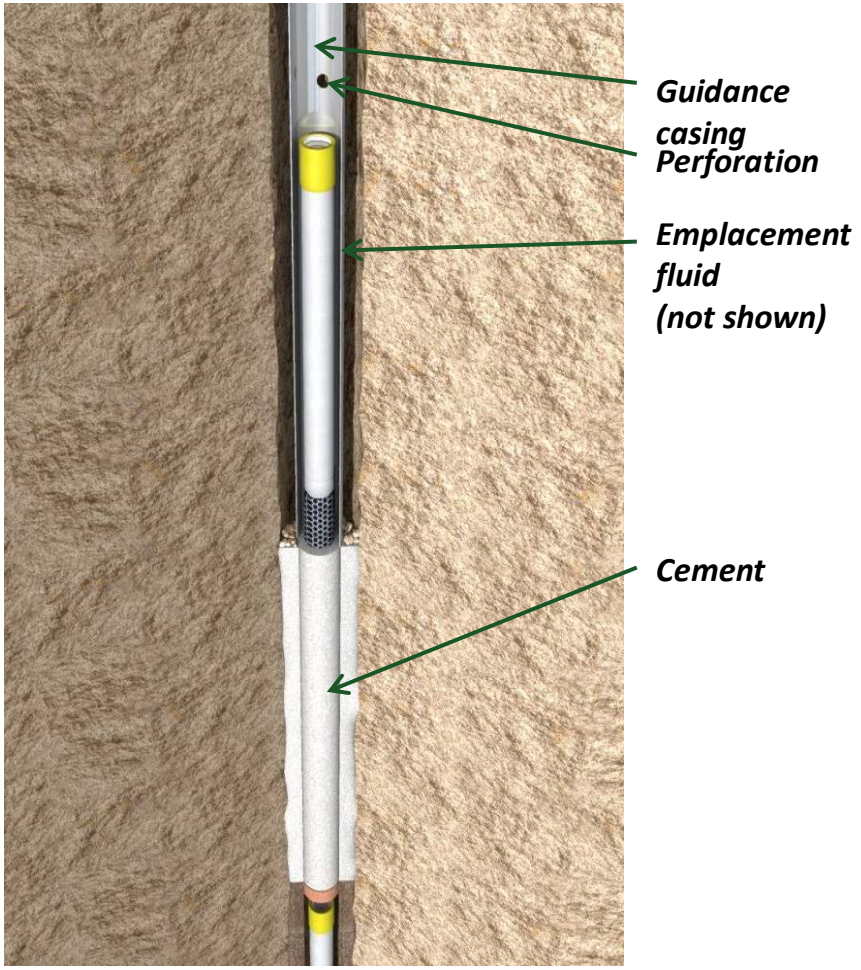
DBFT Engineering Overview: Emplacement Zone Completion Options

Components

- Guidance casing
- **Perforations** in casing
- Emplacement fluid
- Cement

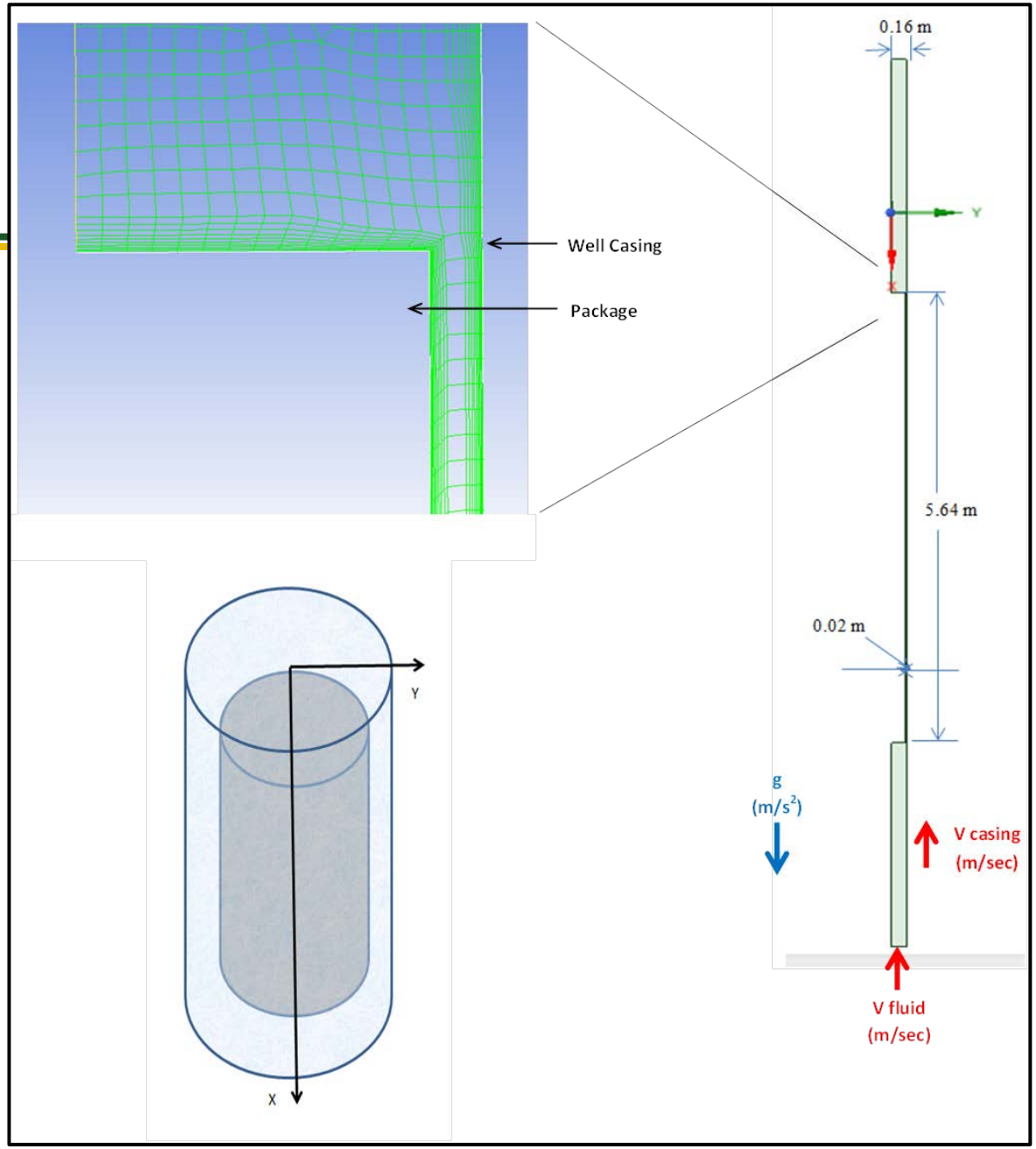
Options

1. Gravity-poured cement plugs
2. Squeezed cement plugs
3. Fully cemented guidance casing w/ gravity-poured plugs
4. Fully cemented emplacement



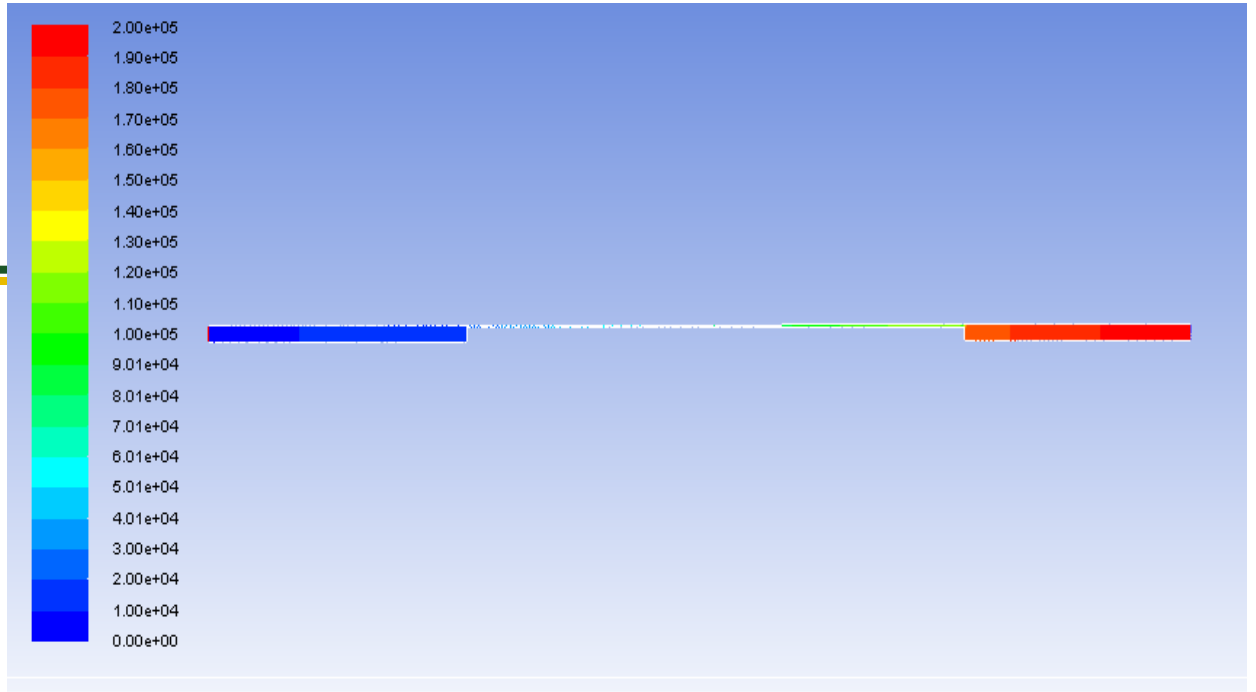
Terminal Velocity Scoping Model Setup

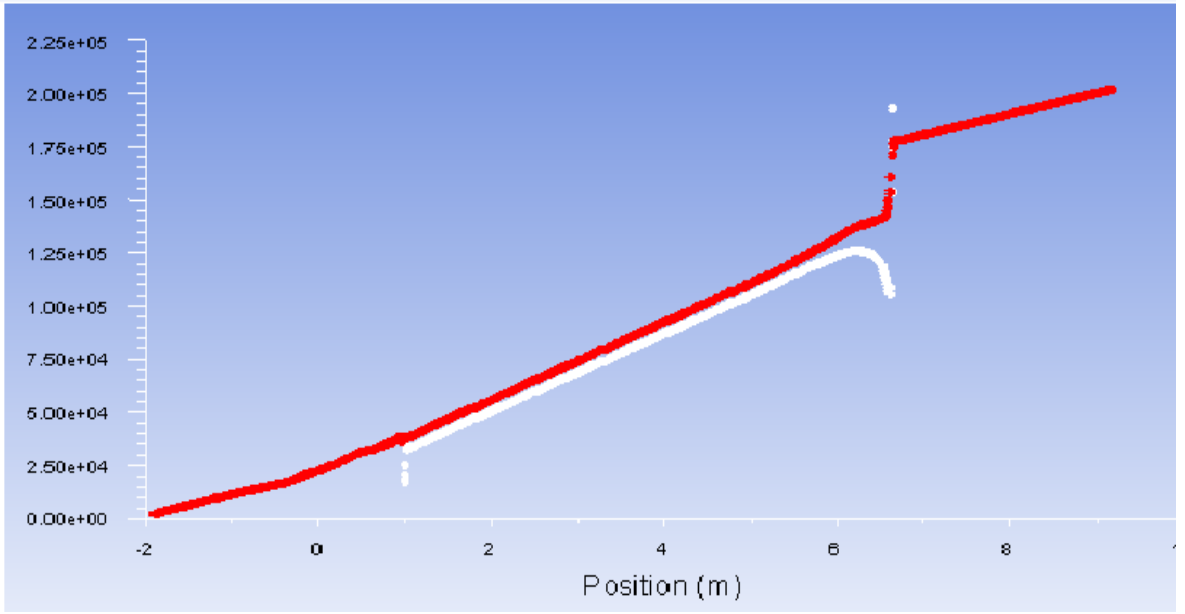
- CFD (ANSYS-Fluent®)
- Axisymmetric, package centered in casing
- Lagrangian Frame
- Reynolds Number 300 to 5.6×10^4 (water @20°C)



Terminal Velocity in Unperforated Casing

- **Radial Gap 2 cm**
  - Package OD 11”
  - Casing ID 12.6”
- **Dominated by Form Drag**
  - Viscous effect ~5%
  - Sensitive to fluid density
- **Uniform Dynamic Pressure**
- **Max. Terminal Velocity ~11 m/sec**
  - Use borehole dia. (no casing)

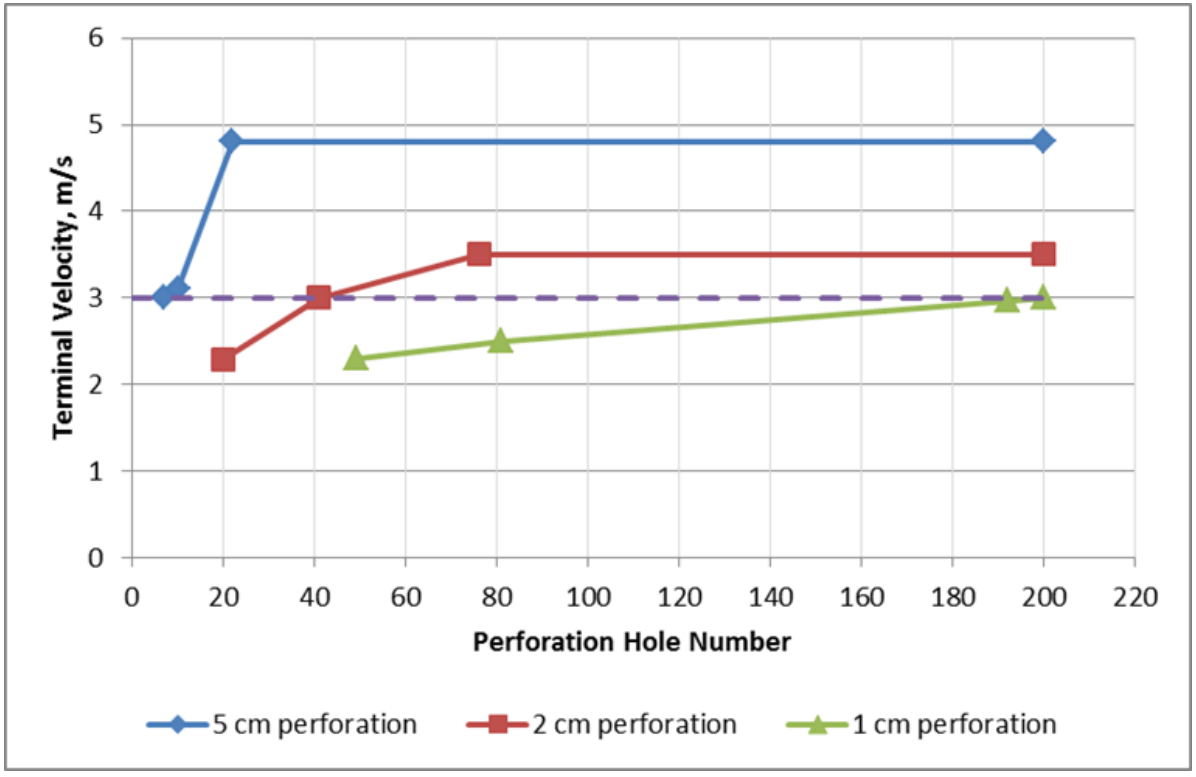


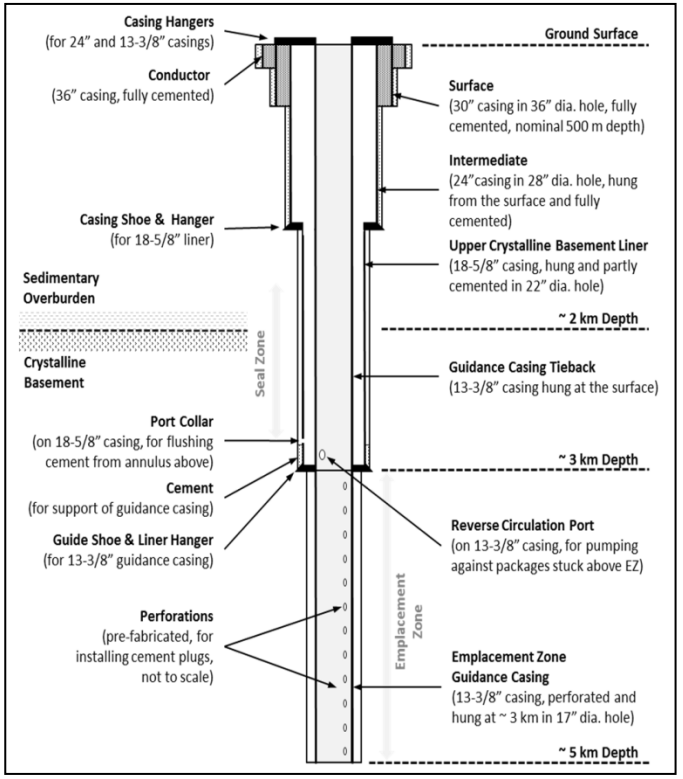


Guidance Casing Perforation Effect and Design for DBFT Free Drop Test

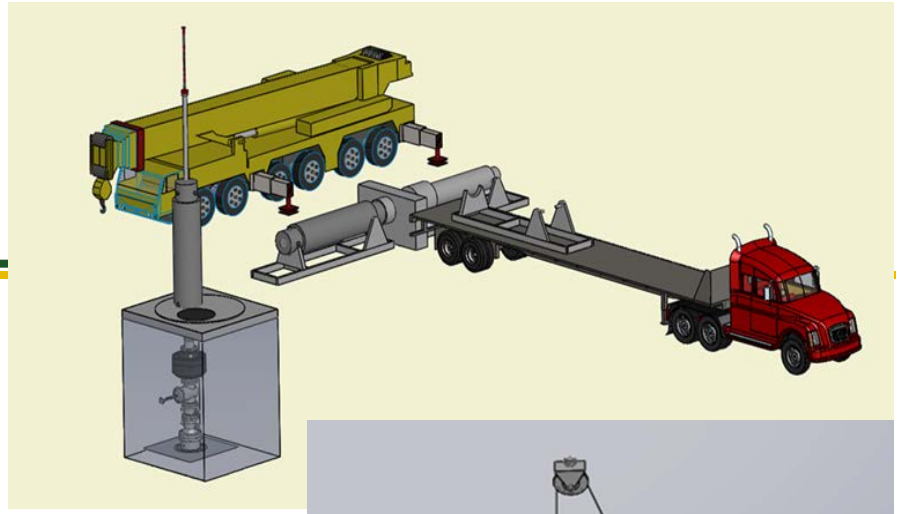
- **Need Small Perforations to Relieve Post-Closure Pressure, and Larger Perforations for Cementing Casing**

How many, what size, and what distribution for DBFT?

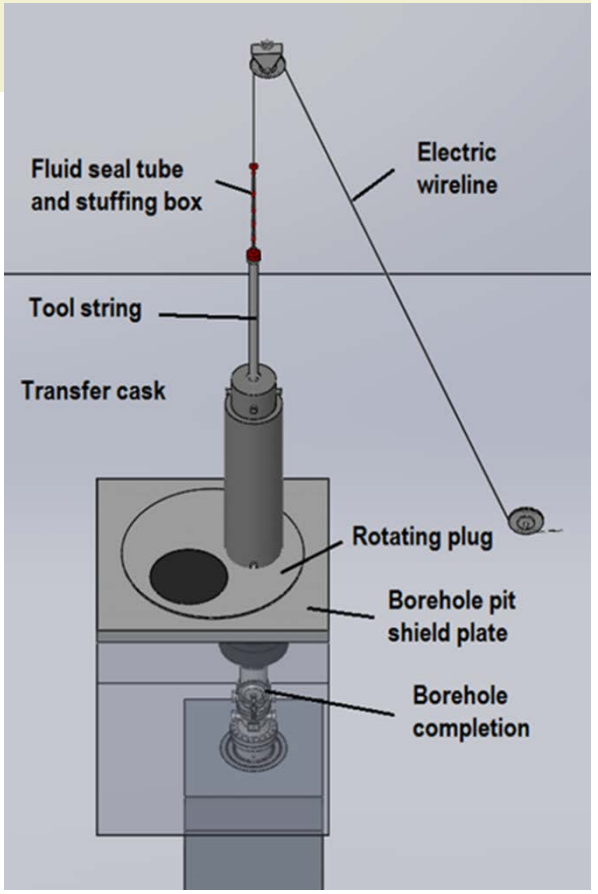




Surface Handling/ Transfer Concept



- Existing Transportation Cask (NAC Legal-Weight-Truck)
- Double-Ended Transfer Cask
- Horizontal Transfer From/To Transport Cask
- Shielded Pit Over Borehole
- Rotating Carousel Shield Over Wellhead
- Remotely Operated Mechanism for Handling Lower Shield Plug in Pit
- Remotely Operated Grayloc Flange in Pit
- Transfer Cask and Attachments <u>Part of Well Control Pressure Envelope</u>



DBFT Engineering Overview: Summary and Status

- **Conceptual Design Complete**
  - Wireline emplacement/retrieval
  - Test packages + instrumentation package (6-axis motion)
  - Electromechanical release and impact limiters
  - Surface handling/transfer system (mockup where appropriate)
  - Well control capability
- **Engineering Services Contractor**
  - Preliminary and final design (FY17+)
  - Fabrication and testing (FY18)
  - Integrated Test Facility (FY19)
  - DBFT field demonstration (FY19)

"A practical concept that will work"

DBFT Engineering Overview
Backup Slides

DBFT Engineering Overview: Packaging Concept Summary Data

WP Type	Waste Type	Casing Grade	Tube OD (in)	Tube ID (in)	Tube D/t Ratio	Connection				
						ID (in)	OD (in)	Casing Size [A] (in)	Casing ID [A] (in)	Radial Gap [B] (in)
Internal semi-flush	Cs/Sr capsules (end-to-end)	P110	5.00	3.88	8.9	3.80	5.00	7.00	6.37	0.68
Internal semi-flush	Cs/Sr capsules (3-packs) [C]	P110	8.63	6.75	9.2	6.67	9.04	10.75	10.05	0.50
Flask-type	Bulk waste (e.g., calcine)	Q125	10.75	8.65	10.2	4.75 [D]	10.75	13.37	12.62	0.93

Notes:

[A] Guidance casing selected for mechanical support and minimal differential pressure.

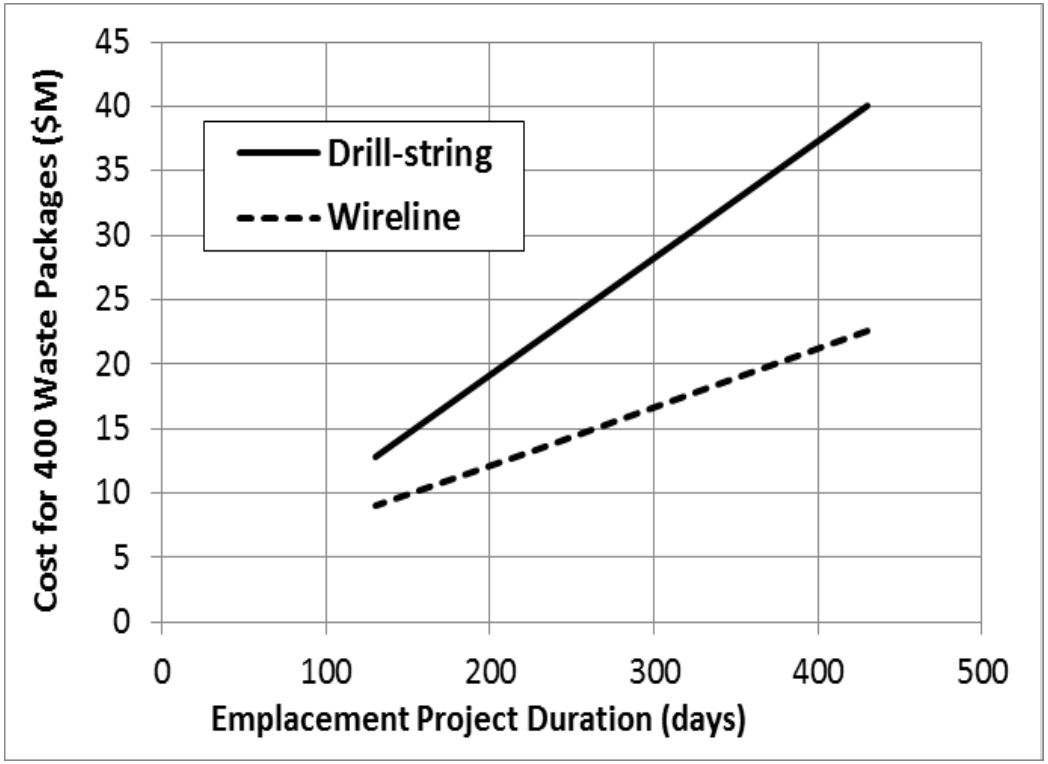
[B] Minimum gap along the length of a package including end connections, based on nominal dimensions, for use with sinking velocity calculations.

[C] Universal canister (3-pack) OD assumed to be 6.500 inches.

[D] Inner dimension for API NC-77 thread.

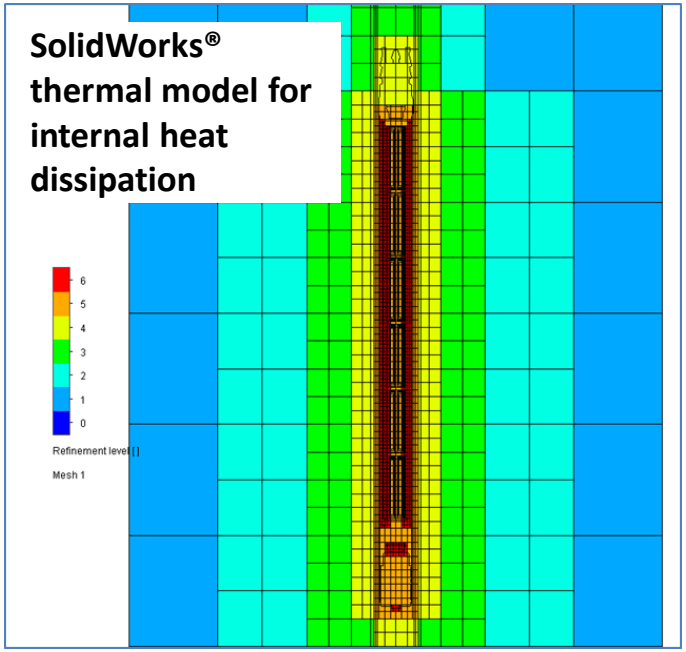
DBFT Engineering Overview: Emplacement Cost Comparative Evalution

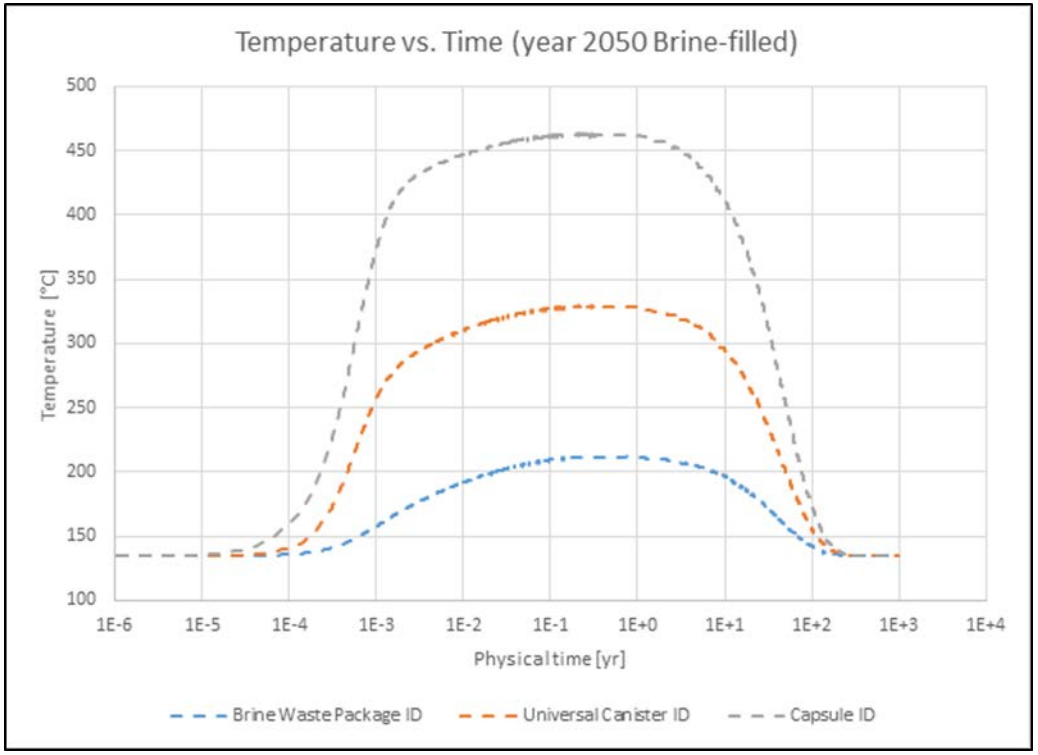
- **Prototypical Operation**
  - One borehole, 400 waste packages
- **Throughput Limited by Delivery of Waste Packages**
  - Loaded/sealed/tested in a hot cell facility
  - Operational experience (WCS, Andrews TX)
  - One package per day



Cs/Sr Capsule Overpack Thermal Analysis

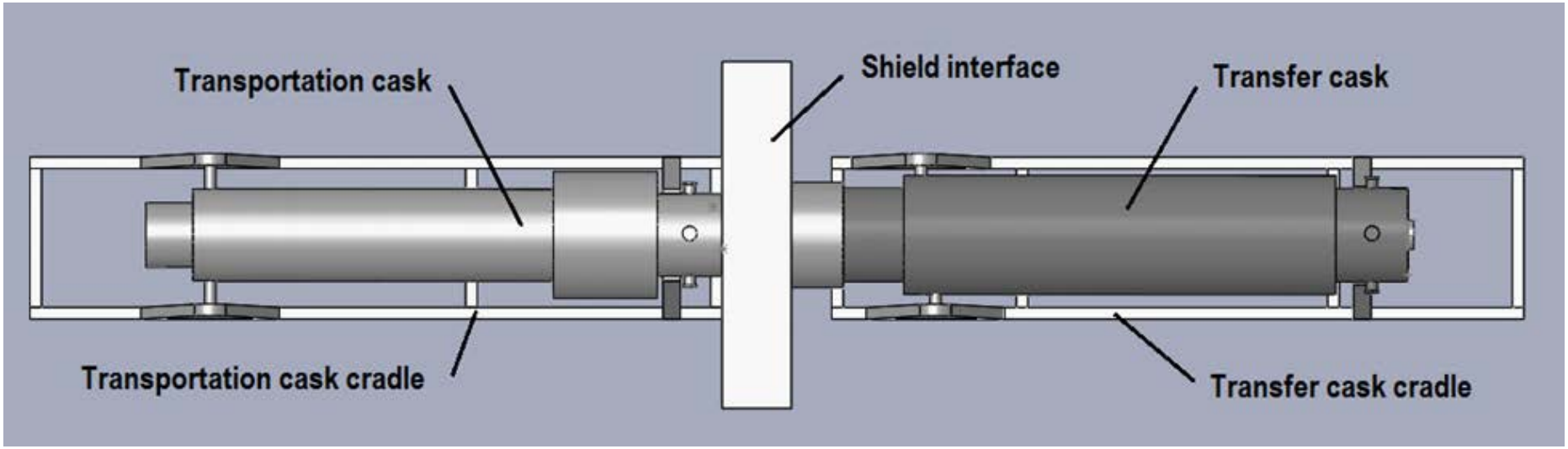
- **Thermal Modeling Results**
  - Overpack ID peak temperature < 250°C
  - Waste form (SrF_2) temperature < 540°C (CsCl limit is 317 °C)





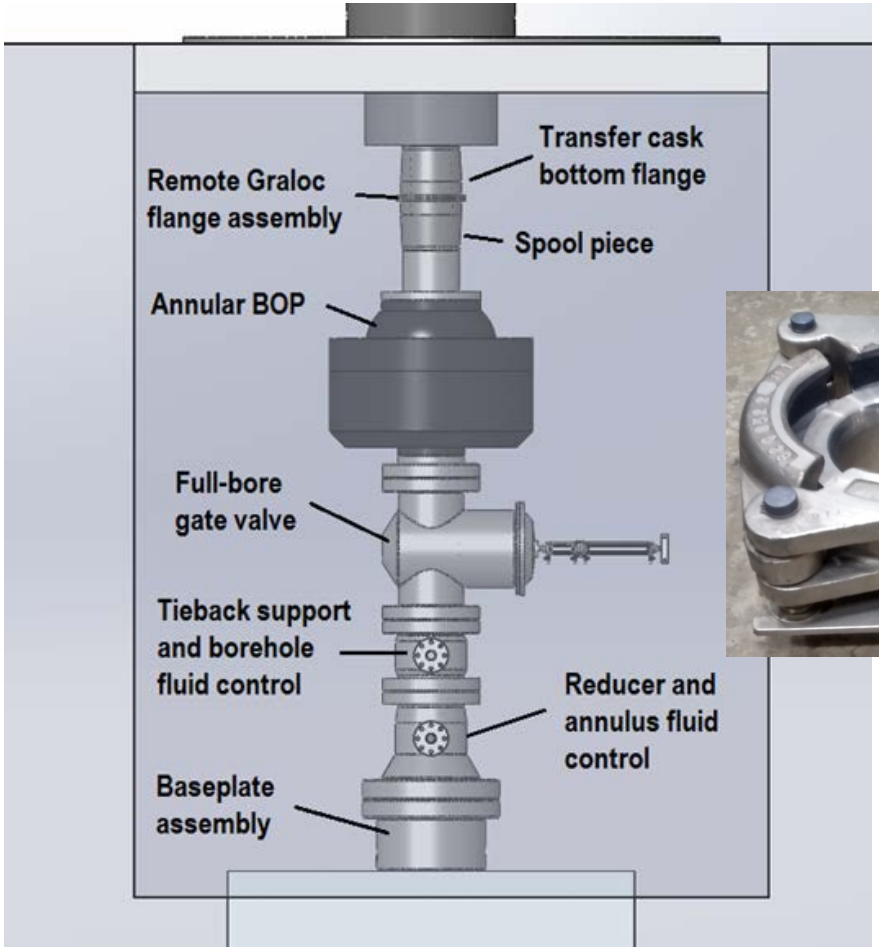
DBFT Engineering Overview: Surface Cask-Cask Transfer Concept

- NAC Legal-Weight-Truck Transportation Cask
- Purpose-Built Double-Ended Transfer Cask
- Sliding Plate Shield Interface for Plug Removal/Replacement and Package Transfer



DBFT Engineering Overview: Transfer Cask – Borehole Interface

- **Pressure-Rated Connection**
- **Grayloc Side-Clamp Flange**
  - Remotely-Operated Mechanism
  - Mounted on transfer cask
  - Also used to remove or replace lower shield plug



6” Grayloc flange locking mechanism



Slide Title

- **Bullets, Numbers, Text, Pictures**

