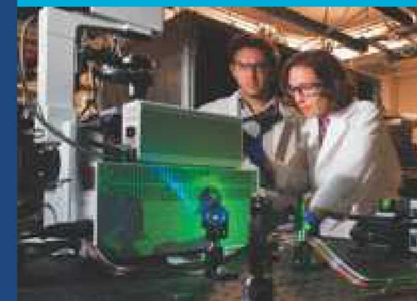
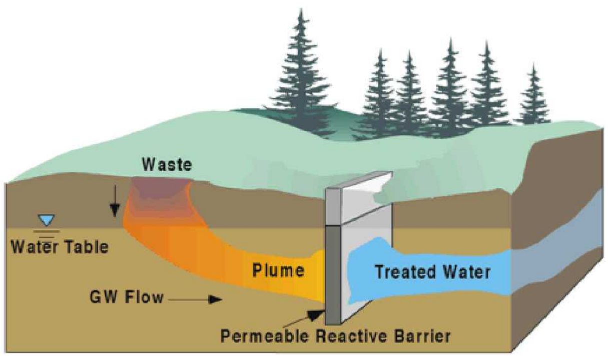
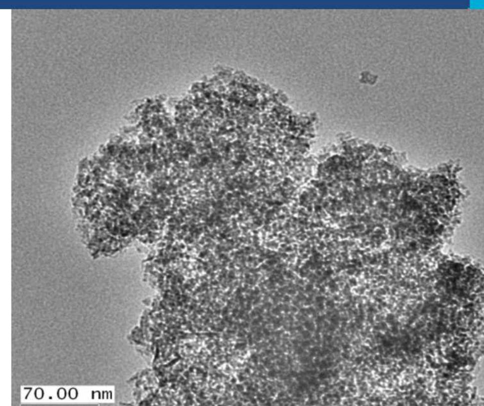
SAND2018-7259PE

Borehole Disposal Workshop







Part 6: Engineering

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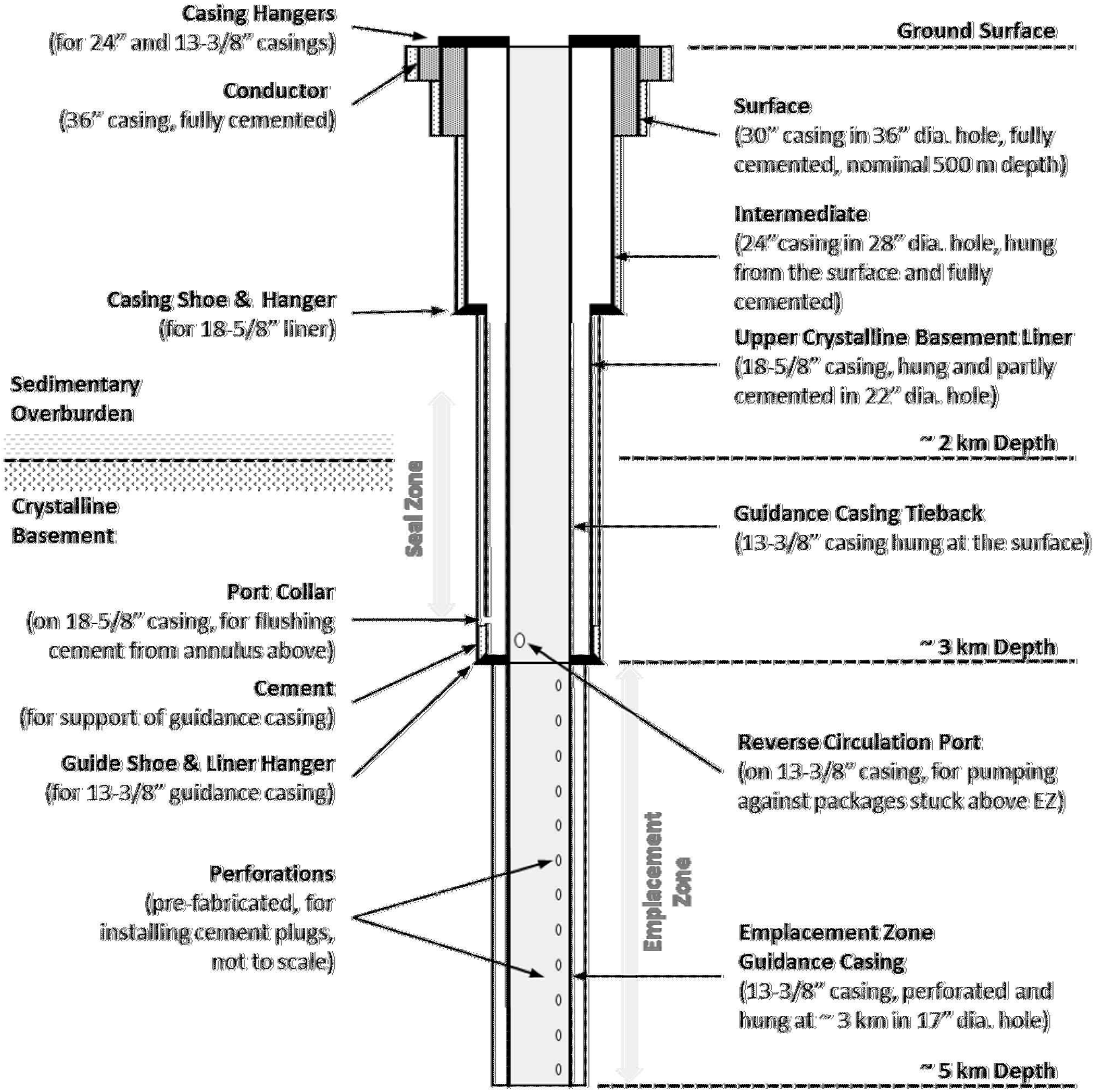
Conceptual Design Process

- Requirements and assumptions
- Borehole construction, wellbore pressure control envelope)
- Waste packaging concepts
- Select representative transportation system (e.g., NAC International LWT® cask)
- Transfer cask concepts
- Define transfer cask: borehole interface
- Select wireline and fluid control components
- Transfer cask shield & wellhead "pit" shield concepts
- Overall equipment arrangement

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)

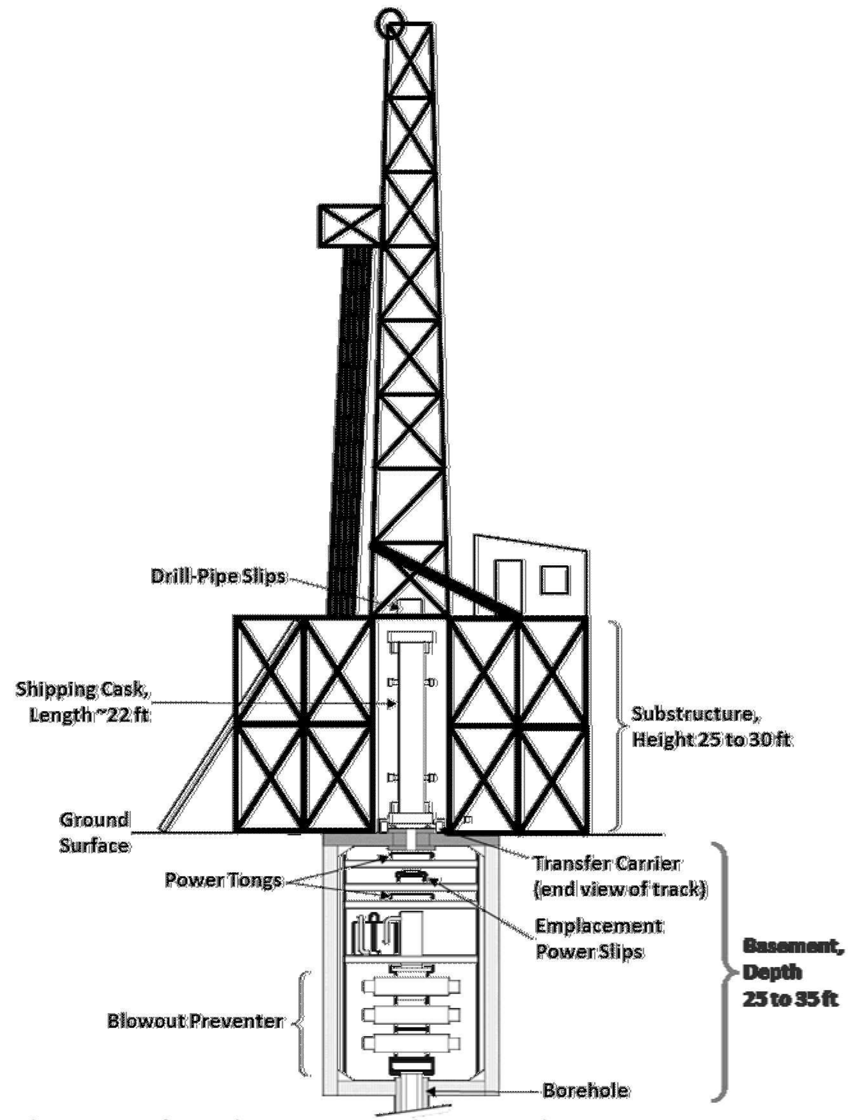


Surface Handling/Equipment Concept

- A concept for safely receiving packages, transferring them to a double-ended cask, positioning the cask over a disposal borehole, and lowering the packages into position at depth
  - Assume availability of the NAC LWT® Type B transportation cask (or equivalent)
  - Purpose-built transfer cask must be double-ended (operable openings at both ends) to lower packages into the borehole
  - Transfer cask would have removable shield plugs on both ends, and would receive a WP from the transportation cask in a horizontal position (which is safest)
  - A side latch mechanism (internal to the transfer cask) would hold the WP in place until ready for lowering into the borehole
  - Wellhead configuration would include a rotating shield plate, and equipment operated remotely beneath it, to remove the lower shield plug and attach the transfer cask to a wellhead flange
  - Once fixed to the wellhead flange, the transfer cask and associated hardware would become part of the pressure envelope for well control (if required)
  - Several options for emplacing WPs in a disposal borehole have been proposed: *drill string*, *wireline*, conveyance casing, coiled tubing, and drop-in

Wire Line and Drill String Emplacement

Schematic of Wireline Emplacement Concept from Climax Test



Schematic of emplacement workover rig, basement, transport carrier, and shipping cask in position for waste emplacement (not to scale)

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

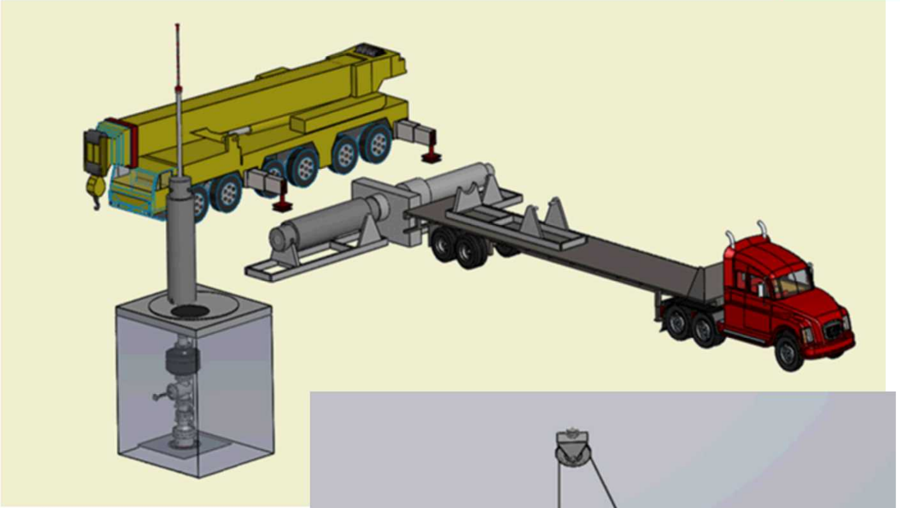
DBFT Engineering Overview: Emplacement Method Cost-Risk Analysis

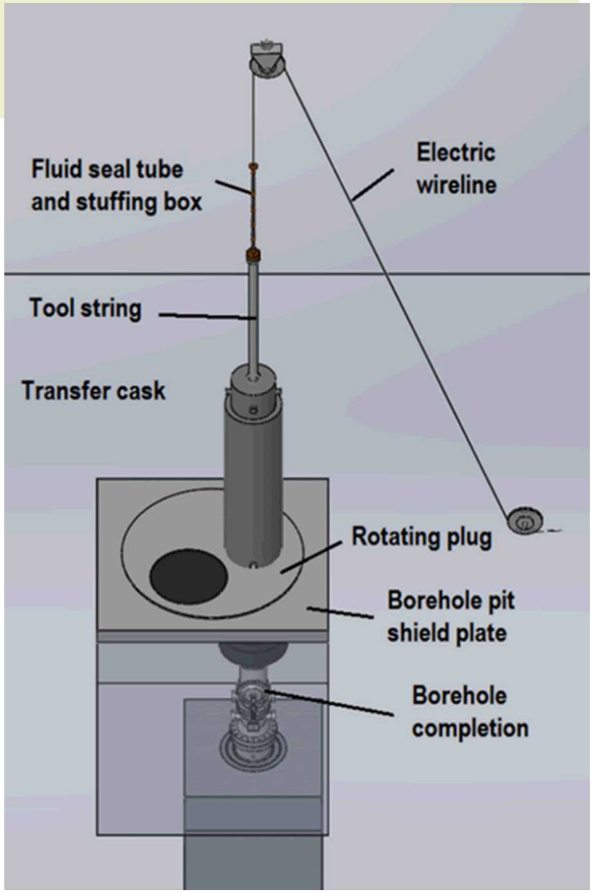
- Results Summary:
  Drill-String Emplacement Would Be ~52× More Likely to Cause a Radiological Release Than Wireline Emplacement
  - Prototype borehole, 400 packages total
  - Assemble and emplace strings of 40 packages

	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.

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 Part of Well Control Pressure Envelope

Typical Type B shipping cask

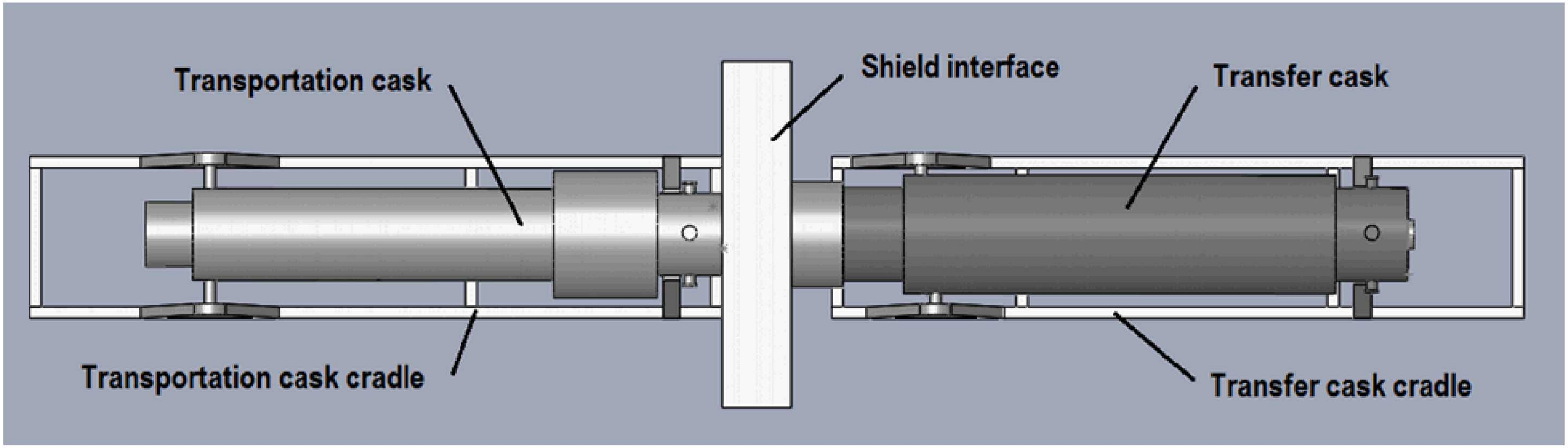
(photo courtesy of Waste Control Specialists)

Each waste package would arrive at the site in a purpose-built Type B shipping cask, on a purpose-built trailer

Purpose-built shipping cask with doors on each end that can be operated remotely by connection to an external power supply. These doors could be electrically operated with worm gear drives

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

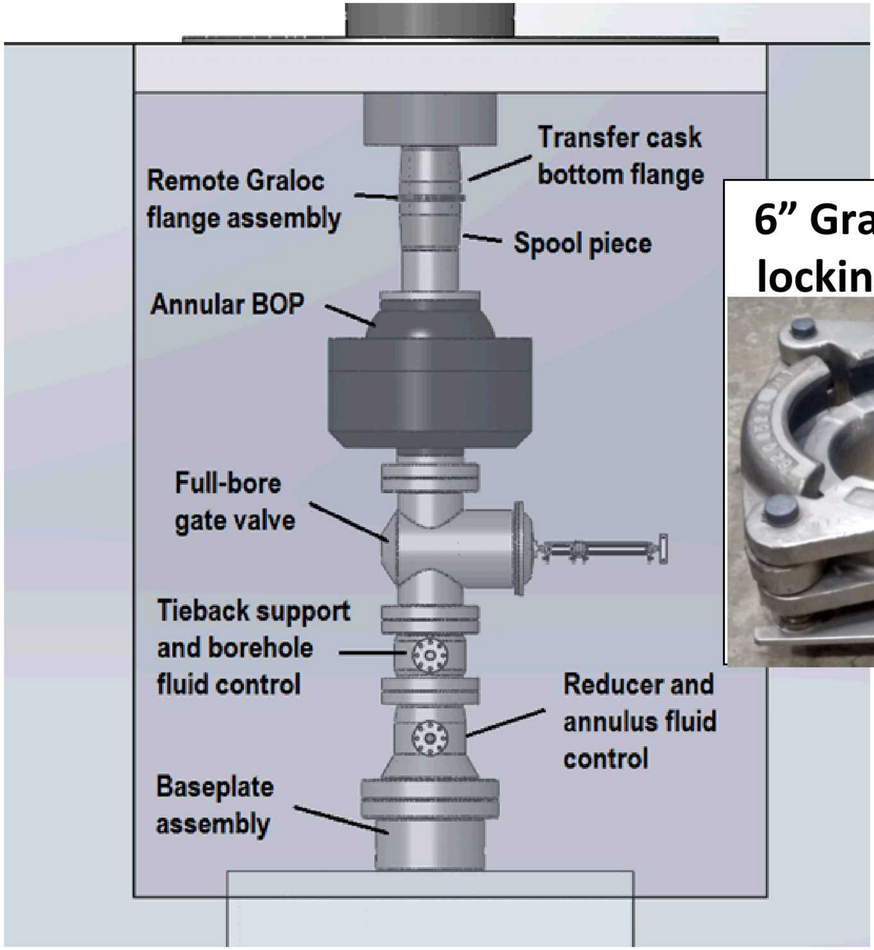


LWT cask being lowered into a horizontal cradle

(ORNL photo)

DBFT Engineering Overview: Transfer Cask – Borehole Interface

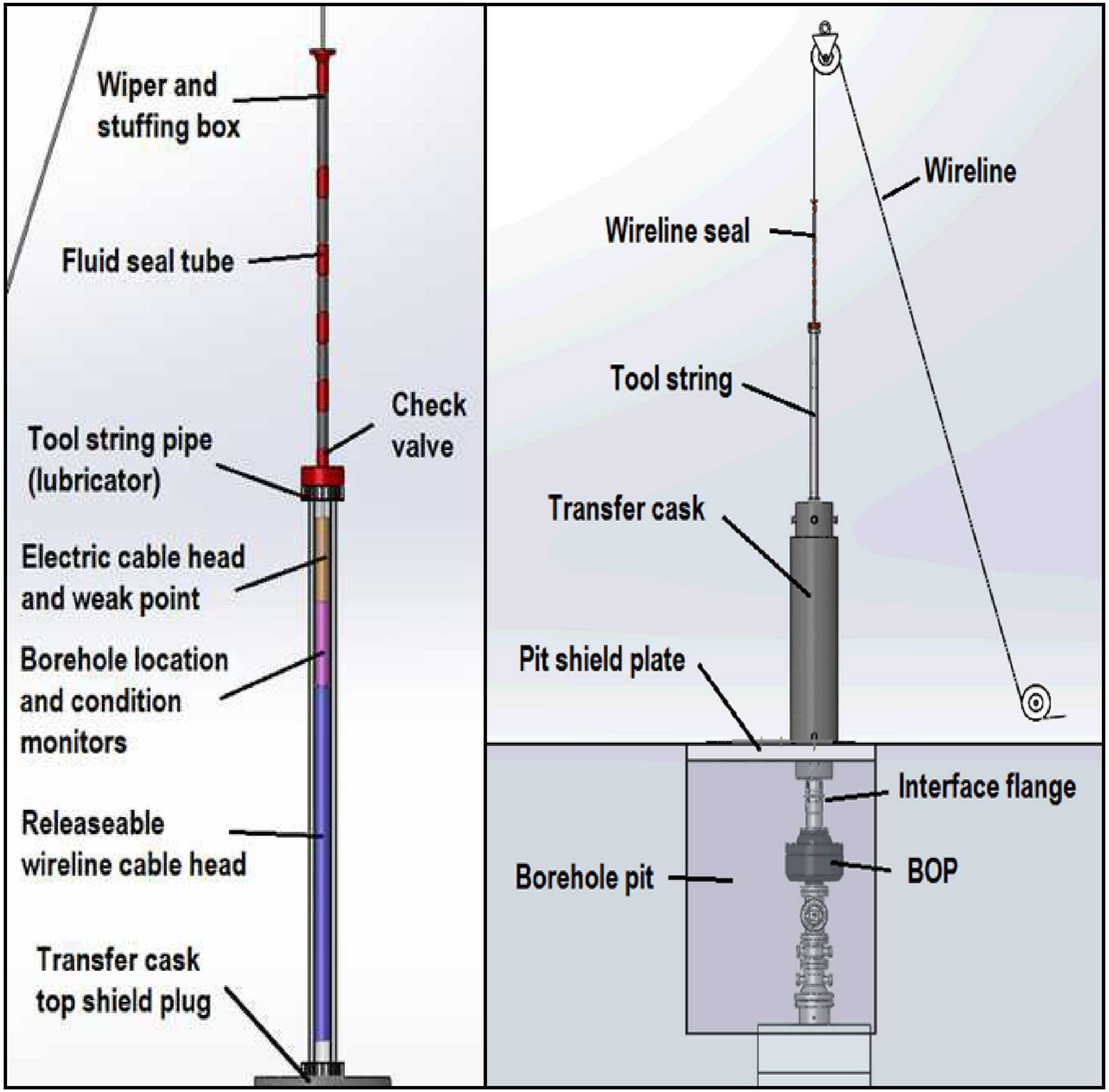
- Pressure-Rated Connection
- Grayloc Side-Clamp Flange
  - Remotely-Operated Mechanism
  - Mounted on transfer cask
  - Also used to remove or replace lower shield plug



6” Grayloc flange & locking mechanism

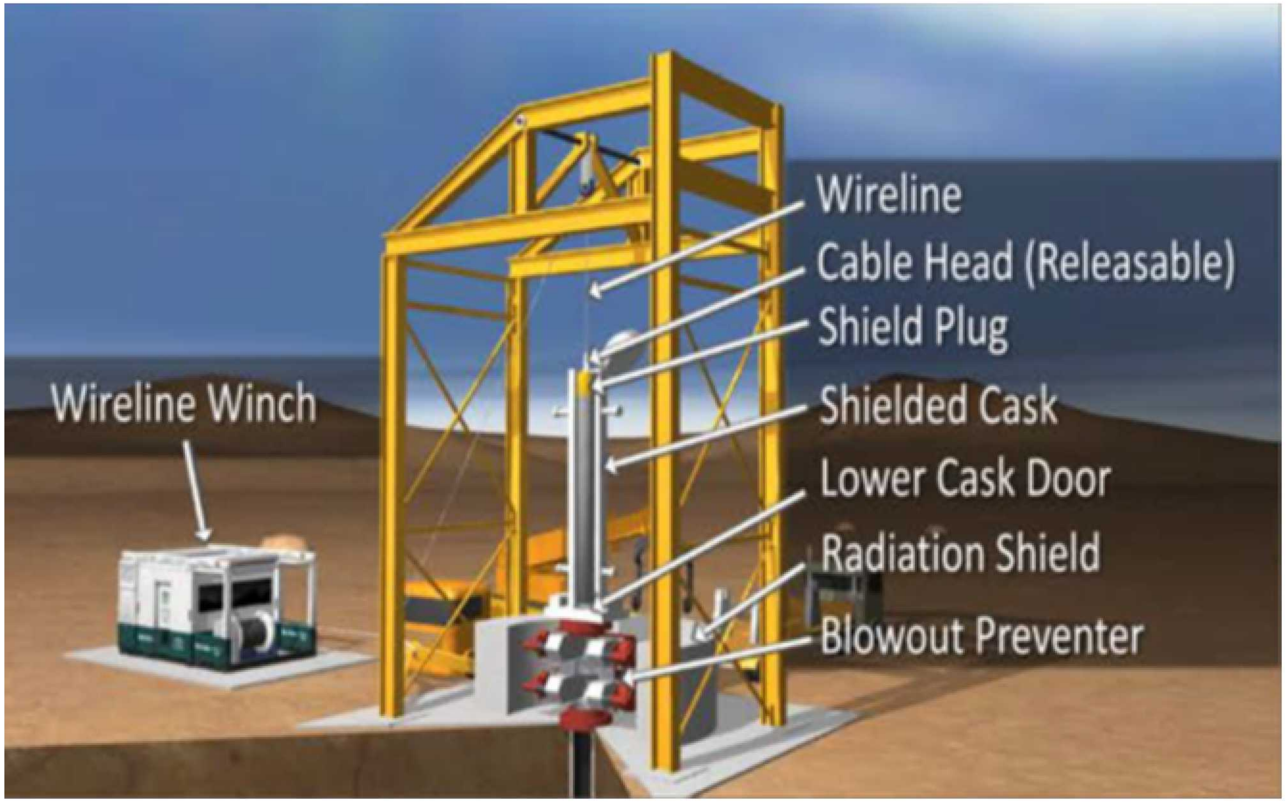
Transfer Cask Upper and Lower Connections

- Maintain Well Control Pressure Envelope
- Lubricator and Grease Tubes Optional

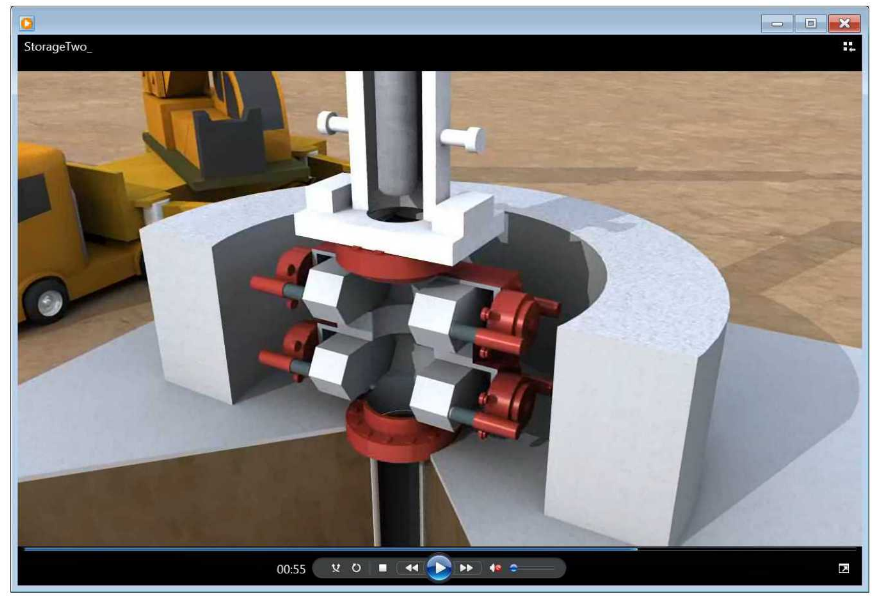


DBFT Engineering Overview: Wireline Emplacement Concept

- Modern Electric Wireline
  - Tuffline® or equiv.
  - 12,000 lb w/out capstan
  - No “seasoning”
- Electro-mechanical Release
- Shielded “Pit”
- Headframe



Wire Line Emplacement

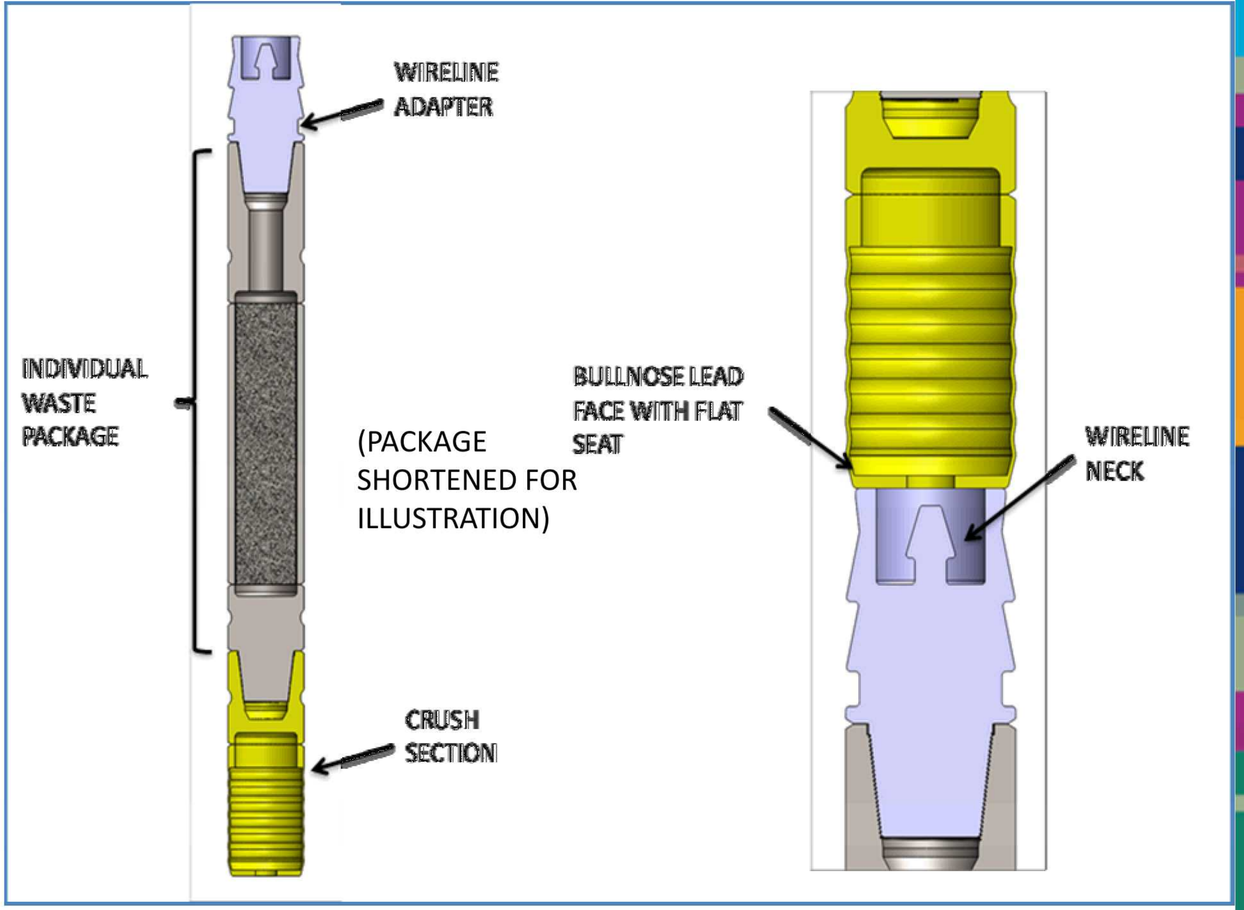


Schematic of BOP shield, top plate and shipping cask in position for waste emplacement (not to scale)

Detail of wellhead inside BOP shield, with doors opening in preparation for lowering waste package

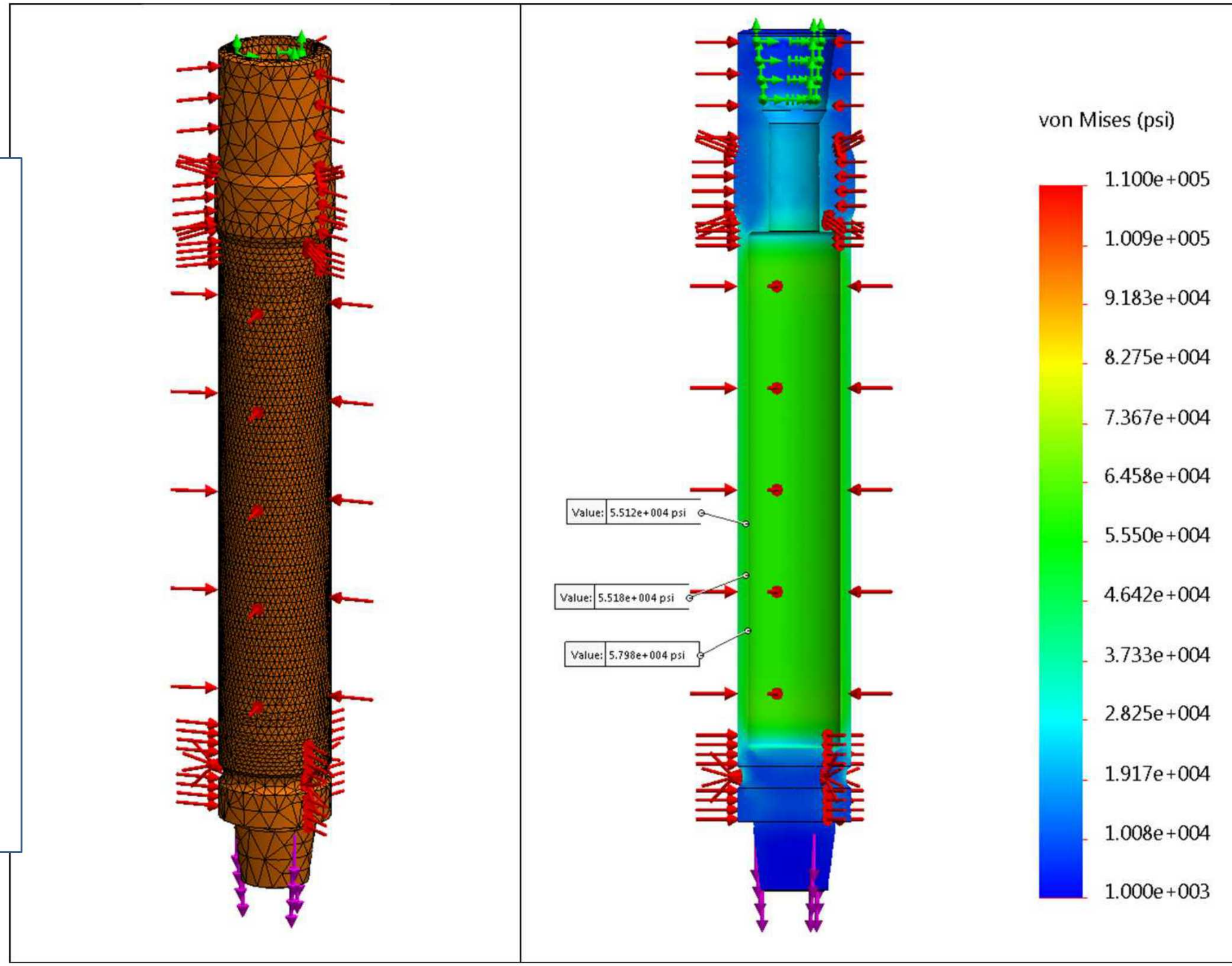
DBFT Engineering Overview: Packaging for Wireline Emplacement

- 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

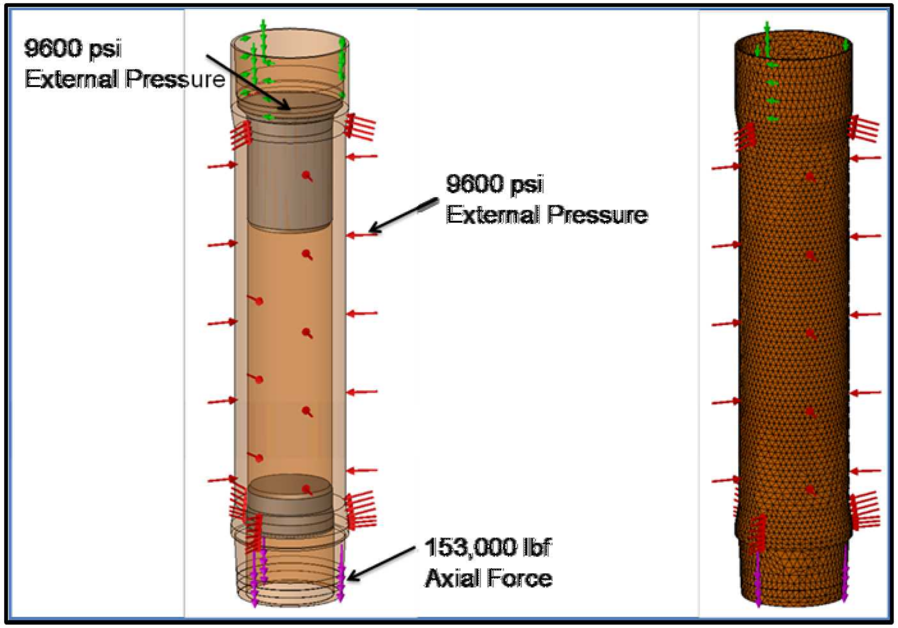
- Flask-Type Shown
- Analyze for
  - 9,560 psi fluid pressure
  - 154,000 lb weight of 40 reference packages
- Axial Compression *Decreases* von Mises Stress

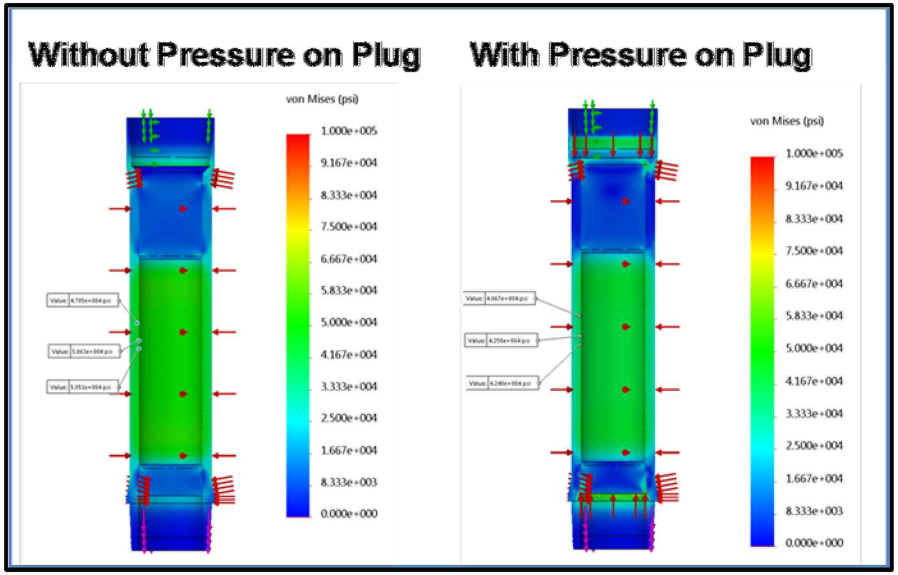


Numerical factor of safety: 2.1 for 110 ksi material

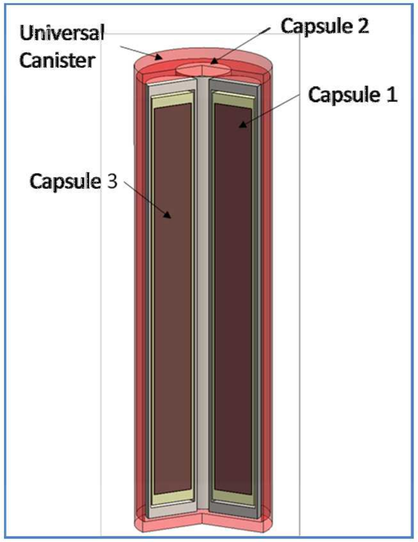
Internal Semi-Flush Disposal Overpack

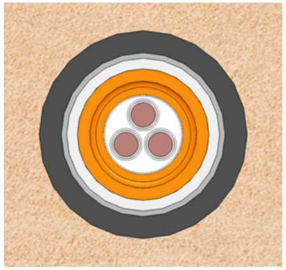
- Tapered Fill Plug (upper shield plug) with Metal-Metal Seal
- Welded & Heat-Treated Lower Plug
- Mating Box & Pin Threads on Attachments
- Take Credit for Casing Threads as Pressure Backup
- Thread Leakage *Decreases* von Mises Stress on Fill Plug



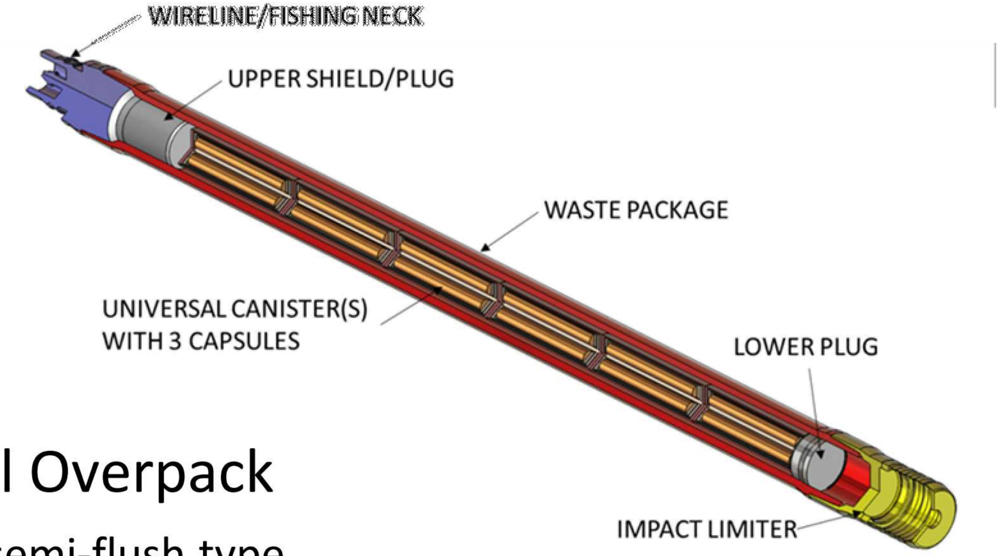


Overpack Concept for Pre-Canistered Cs/Sr Capsules





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

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.

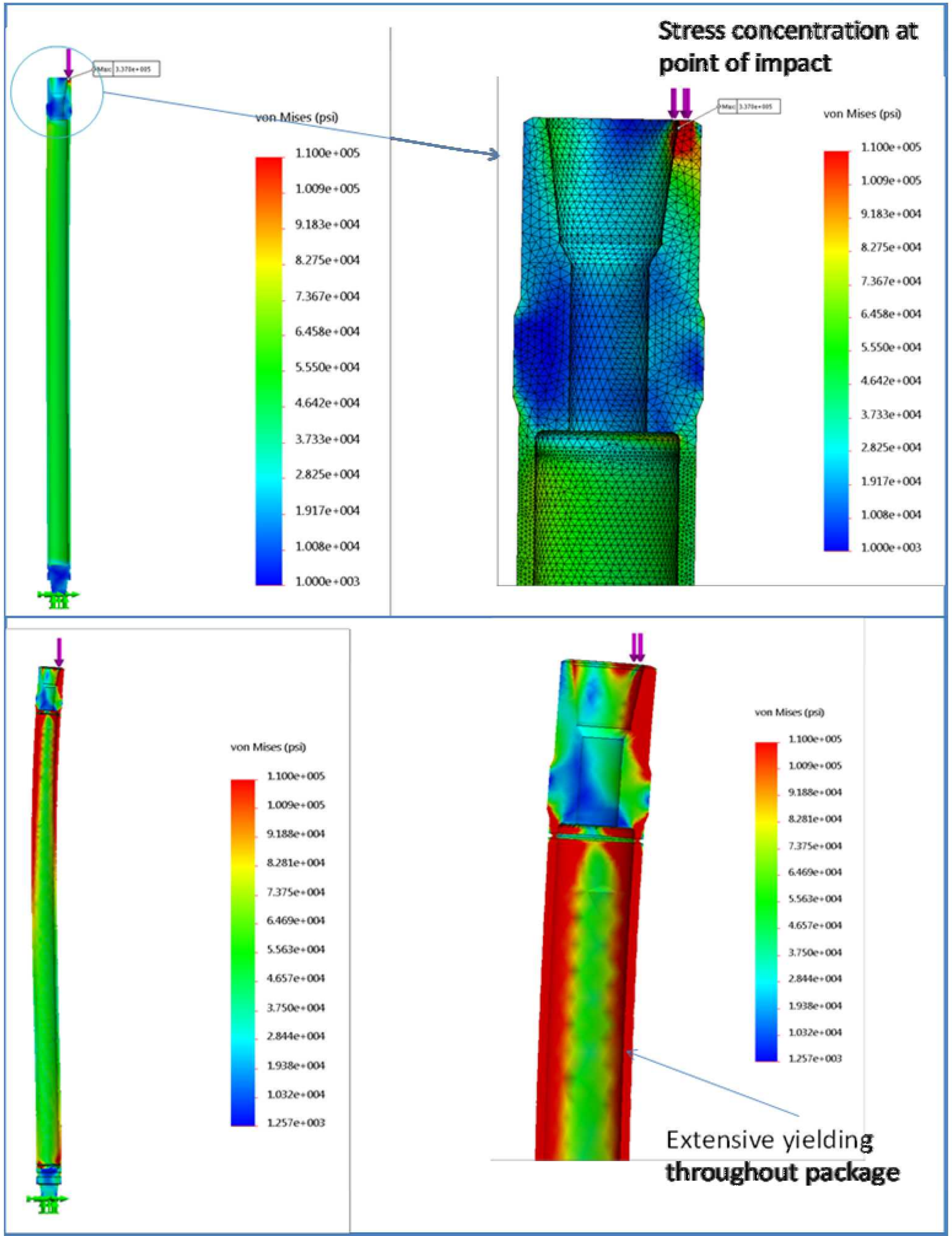
[D] Inner dimension for API NC-77 thread.

Quasi-Static Fragility Analysis for Dropped Packages

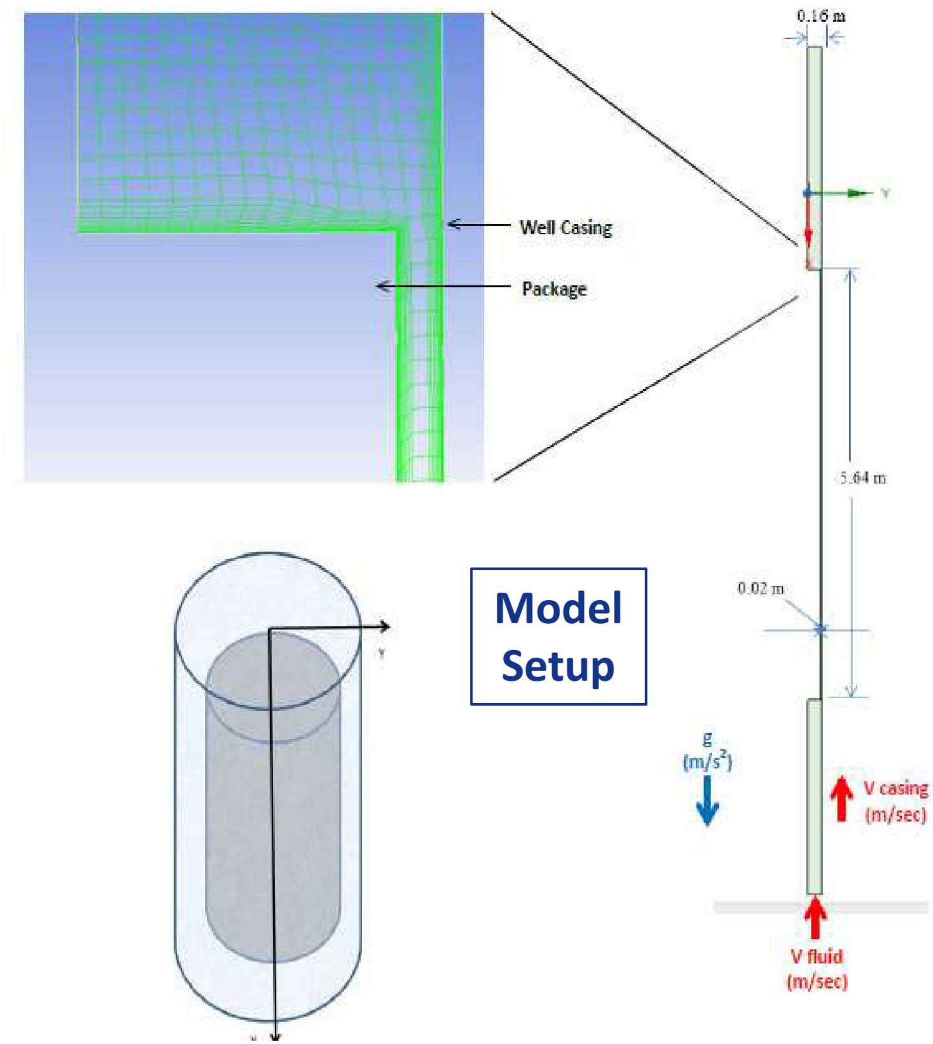
One package dropped at 2.5 m/sec

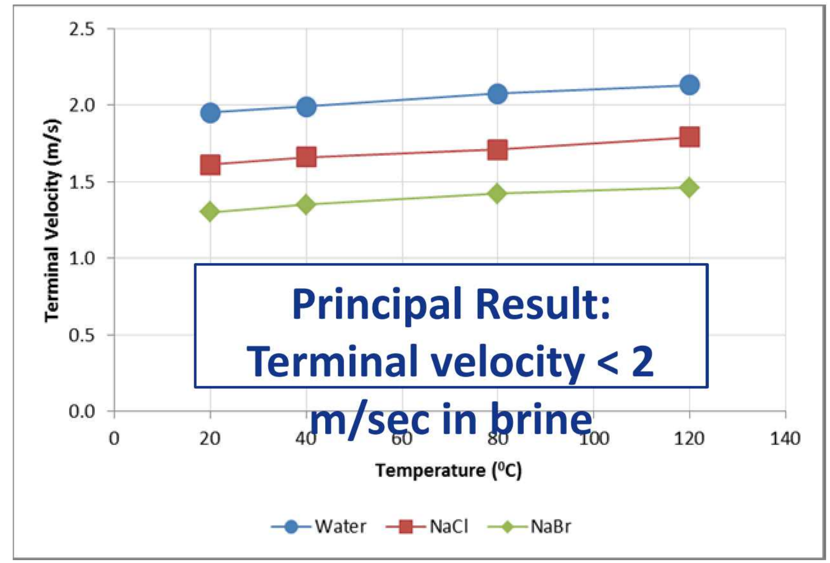
- Quasi-Static Stress Analysis
- Impulsive Force Concentrated Over 40° of Perimeter
- Strings of 1, 5, 10 or 20 Dropped
- von Mises Stress (110 ksi yield)
- 20× Horizontal Exaggeration
- Conclusion: Strings of >1 Package Produce Extensive Yielding

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



Fluid Dynamics Simulation of a Waste Package Falling in a Borehole





Principal Result: Terminal velocity < 2 m/sec in brine

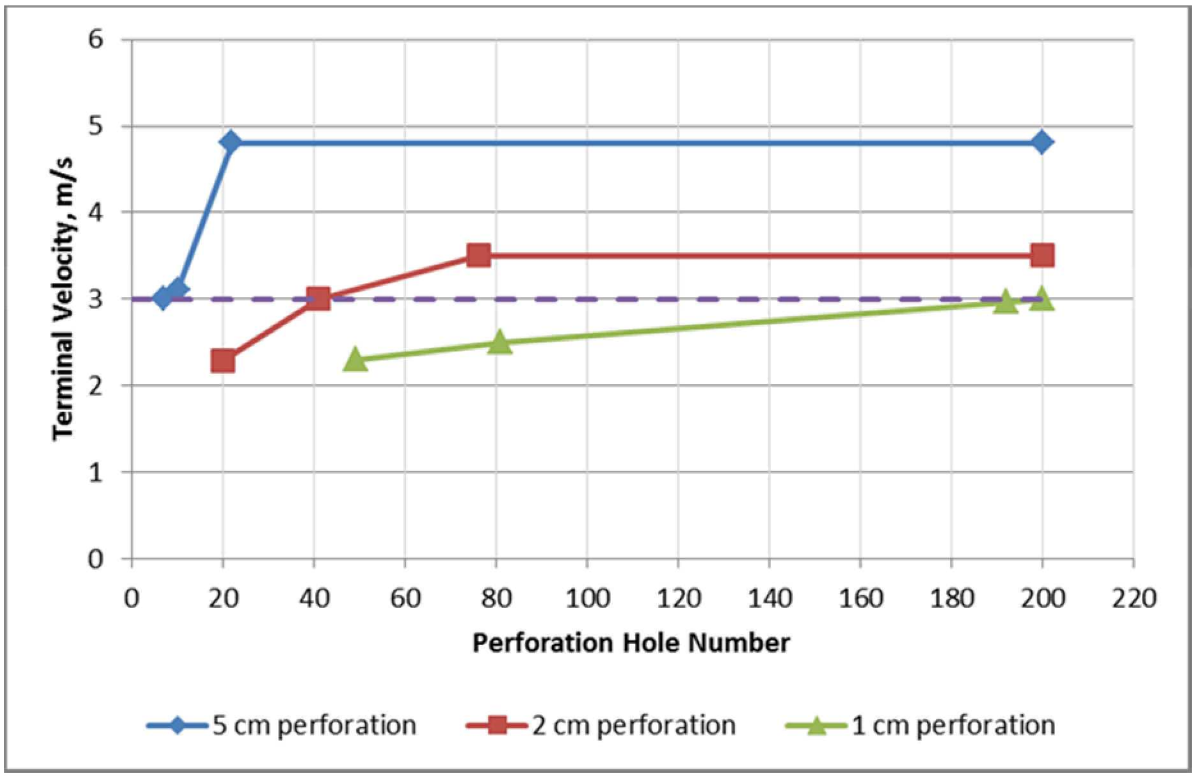
- **Package dia. 28-cm, mass 2,100 kg, 2-cm radial gap**
- **Fluid viscosity has a minor effect on terminal velocity**
- **Density is the major influence**

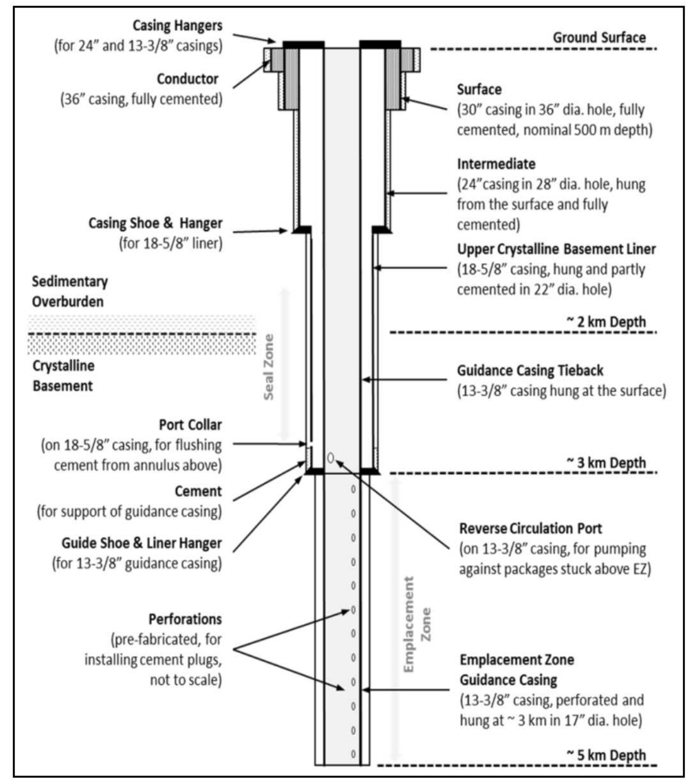
∴ Temperature effect is small

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 of perforations for DBFT?

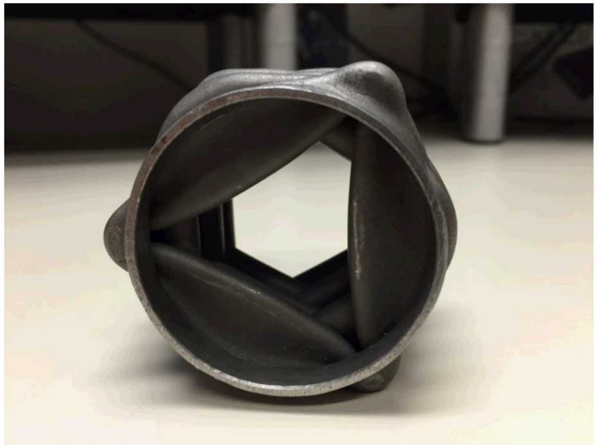




Impact Limiter Example Hanford Multi-Canister Overpack Absorber

- 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



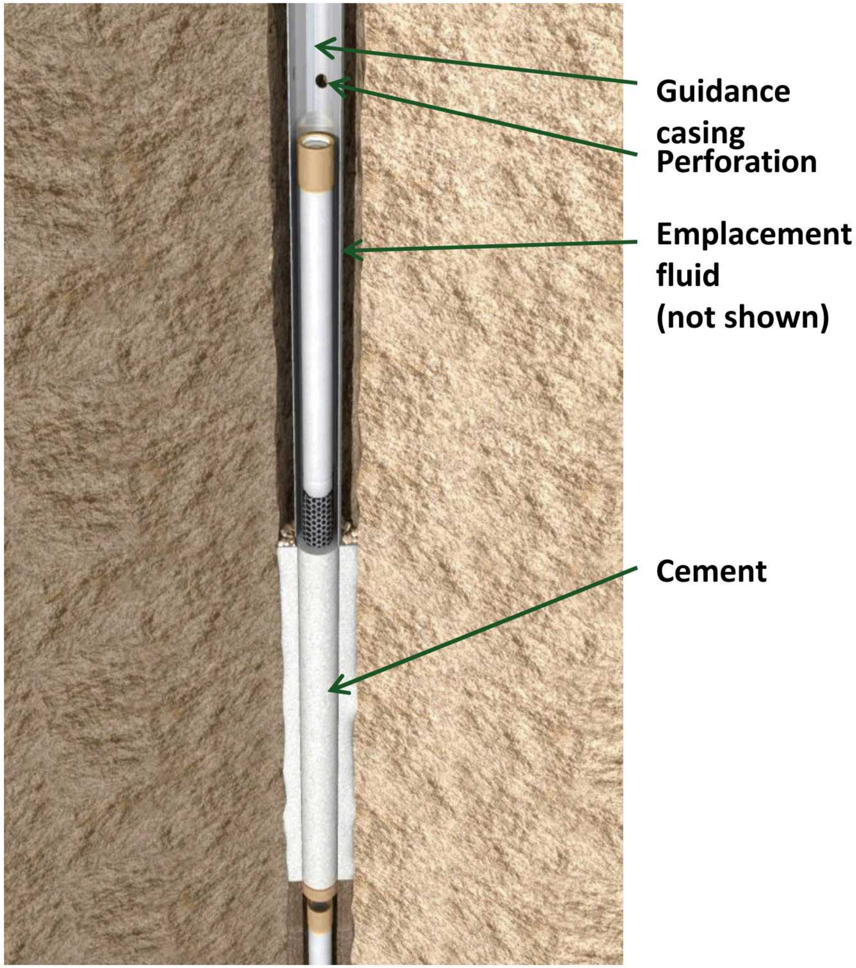
See also:

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

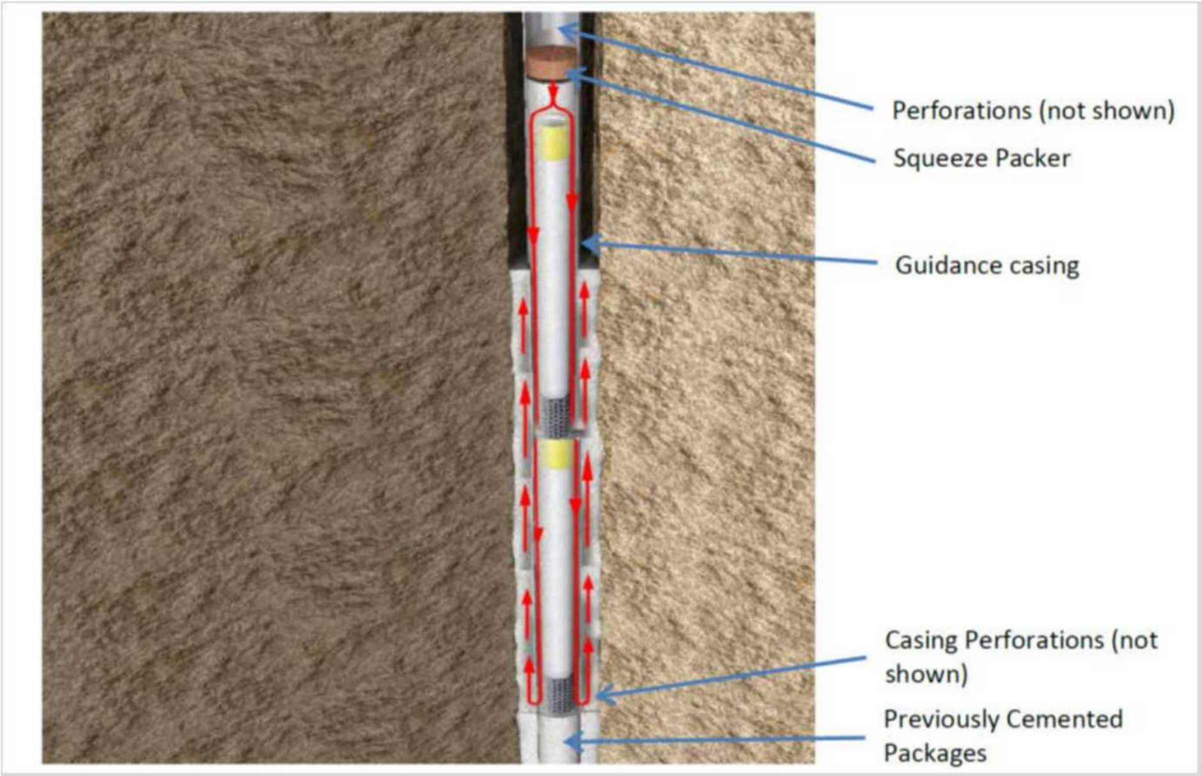
**Photos from:
Brad Day, Sandia National Laboratories, Carlsbad NM.**

DBFT Engineering Overview: Emplacement Zone Completion Options

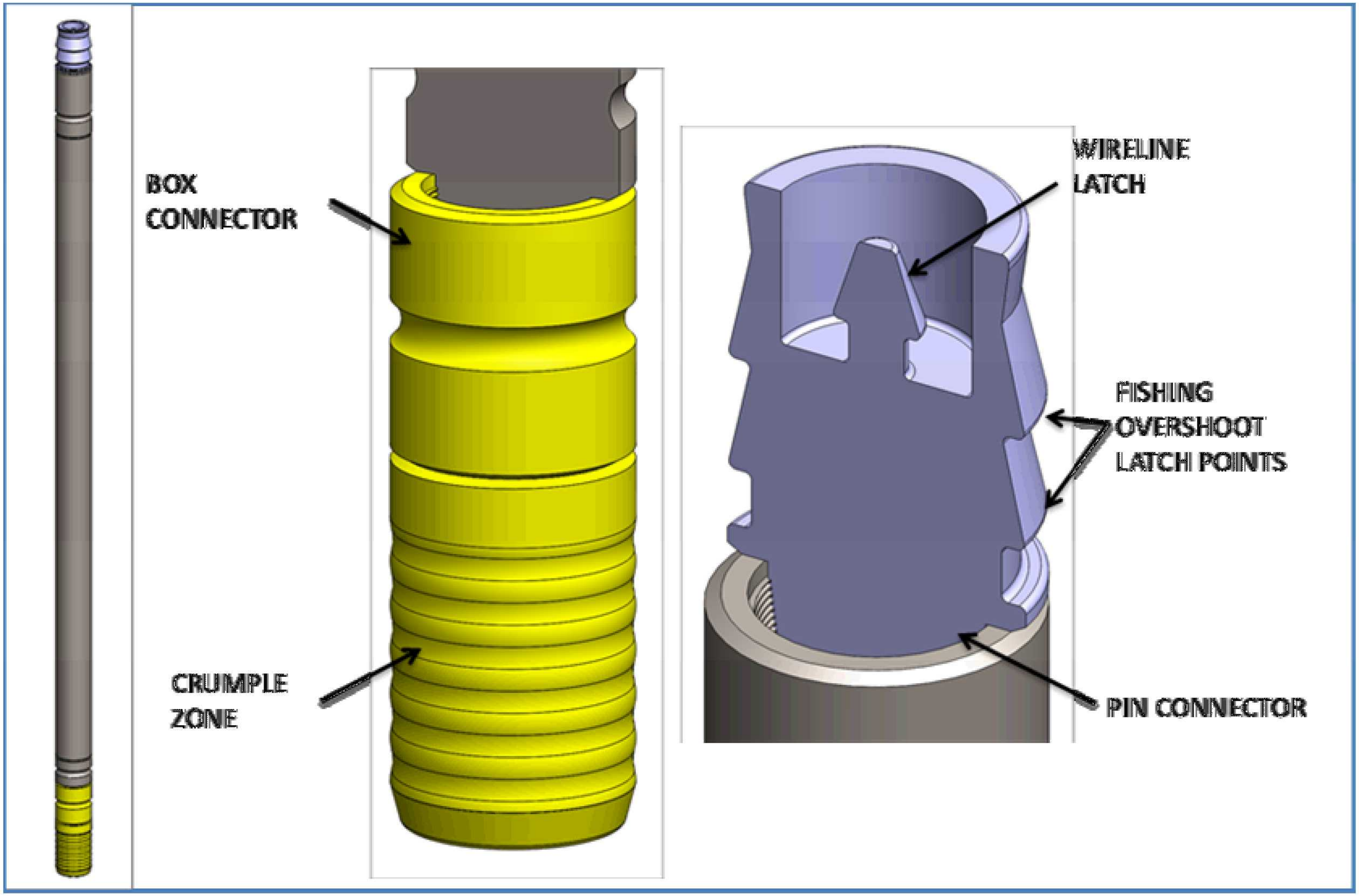
- Components
  - Guidance casing
  - **Perforations** in casing
  - Emplacement fluid
  - Cement
- Options
  1. Gravity-poured cement plugs
  2. Squeezed cement plugs
  3. Fully cemented guidance casing w/ gravity-poured plugs
  4. Fully cemented emplacement



Cementing Packages In Place



Upper and Lower Subs Attached to Each Package, for Wireline Emplacement



Safety of Disposal Operations

- Deep Borehole Field Test vs. Potential Future Disposal System
  – DBFT will have ***zero radiological risk***
- Accident Prevention During Emplacement Operations
  – DBFT conceptual design: safety analysis that discriminates between alternative concepts
- Example Types of Emplacement Accidents (disposal system)
  – Single canister drop in borehole (zero consequence?)
  – Pipe string + waste package string drops in borehole
  – Pipe string drops onto packages
  – Waste packages stuck → Fishing
  – External hazards (seismic, extreme weather)

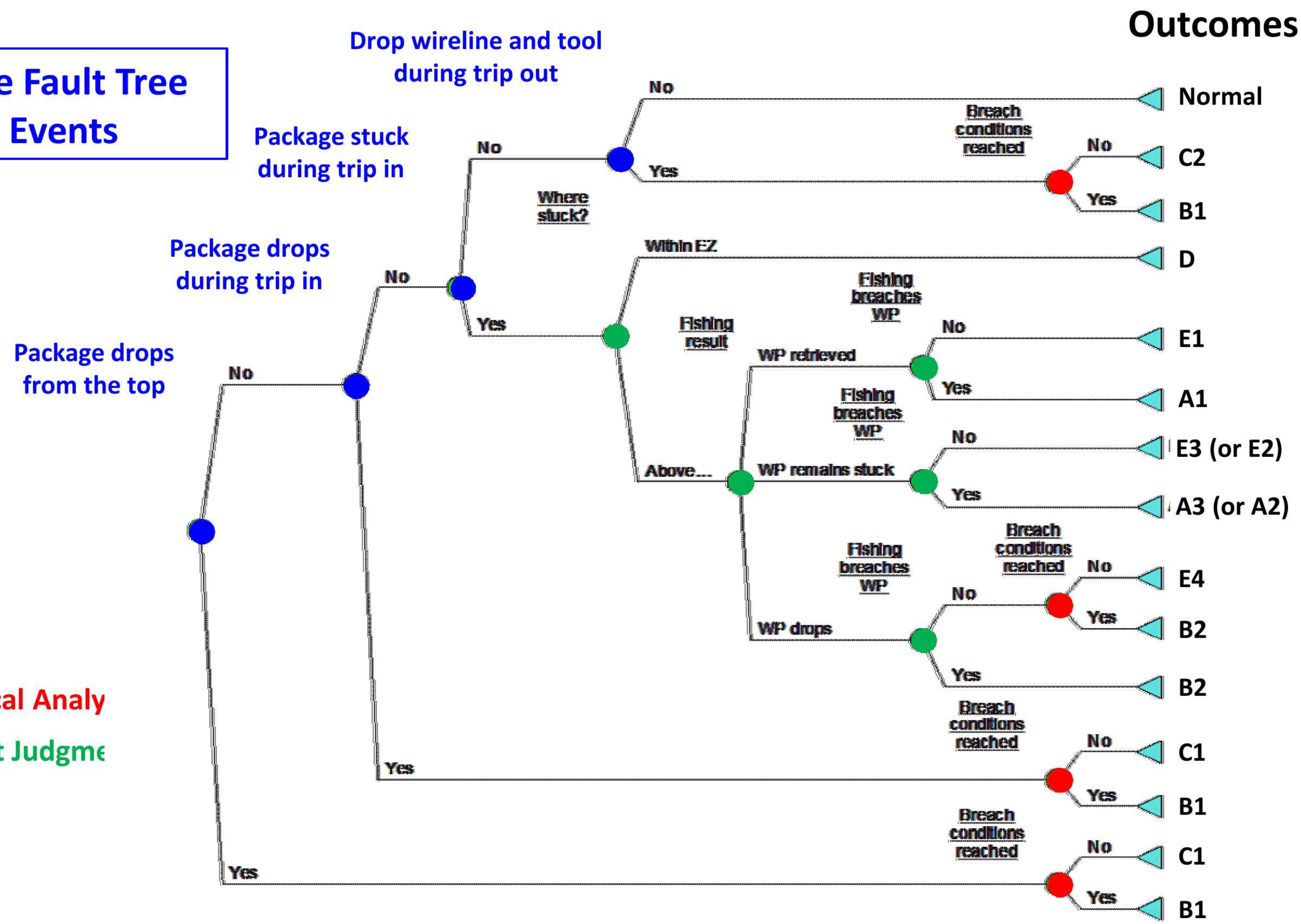
What is the safest emplacement method, given the possible range of accidents/off-normal events?

Cost-Risk Study for Emplacement Concept Selection

- Recommend Emplacement Method for Disposal, Apply to DBFT Demonstration
- Assumptions
  - **Prototypical disposal system**
    - **One borehole**
    - **400 packages in stacks of 40 with cement plugs separating**
    - **Average one package emplaced per day**
  - **Occupational hazards are low and don't discriminate emplacement options (oilfield experience)**
  - **Worker radiological exposures would be low, and don't discriminate emplacement options (industry experience with nuclear material handling)**

Cost-Risk Design Study: Event Tree for Wireline Emplacement

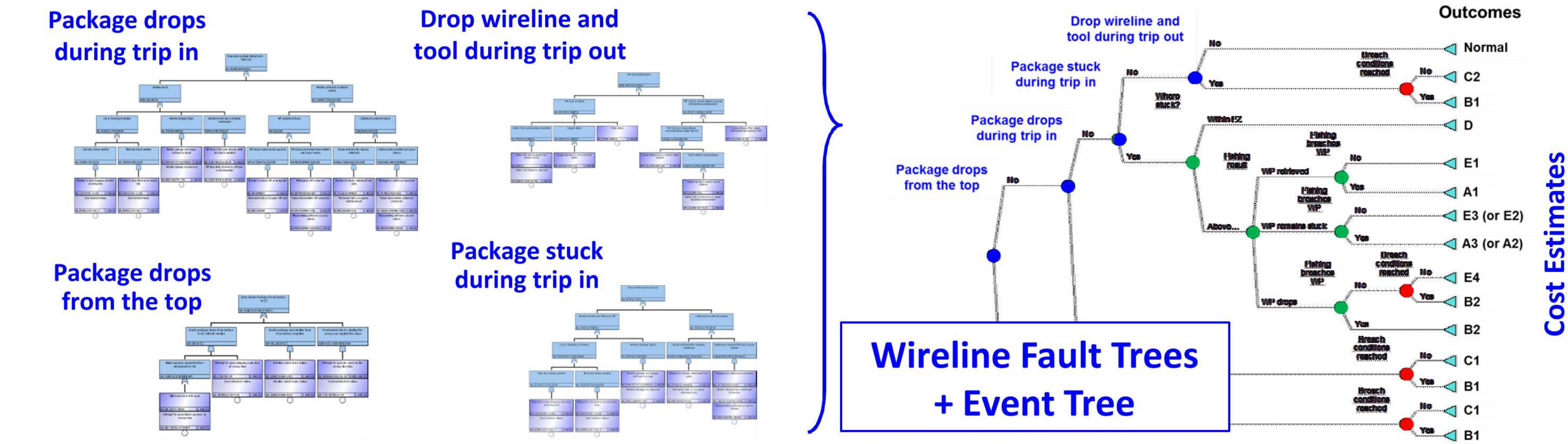
Wireline Fault Tree Top Events

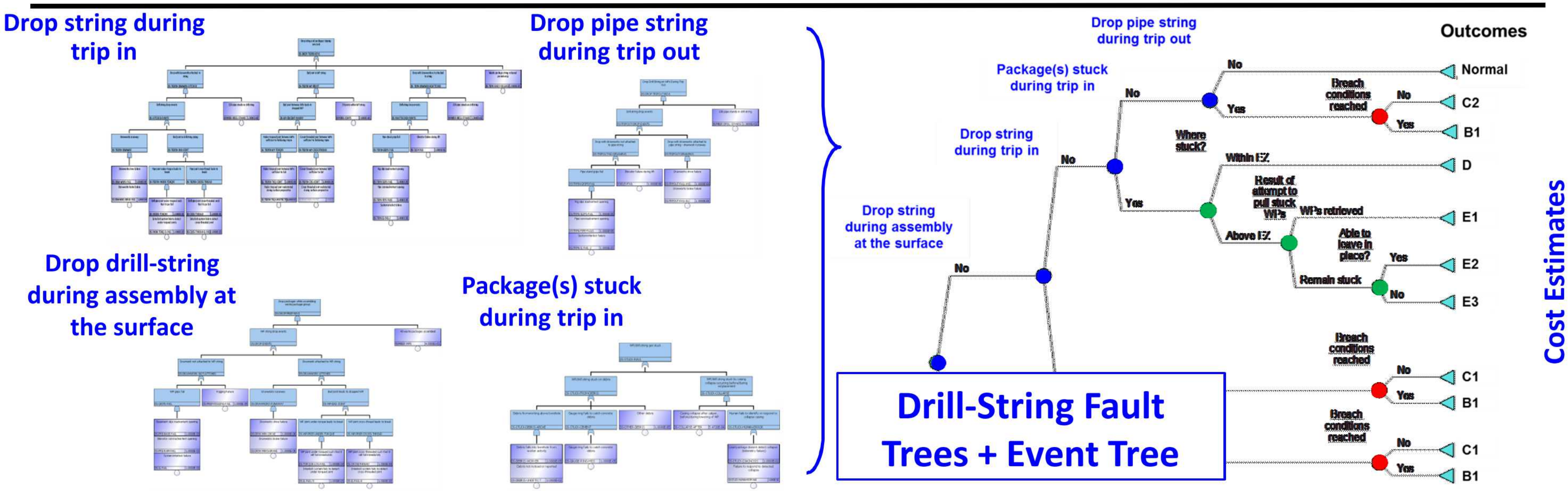


● → Physical Analy

● → Expert Judgme

Cost-Risk Design Study: Cost–Risk Model





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Probability of incident-free emplacement of 400 WPs	**97.83%**	**99.24%**
Approximate total costs if successful ($ million)	**23.5**	**41.9**
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Aggregated probability of radiation release	1.35E-04	7.08E-03

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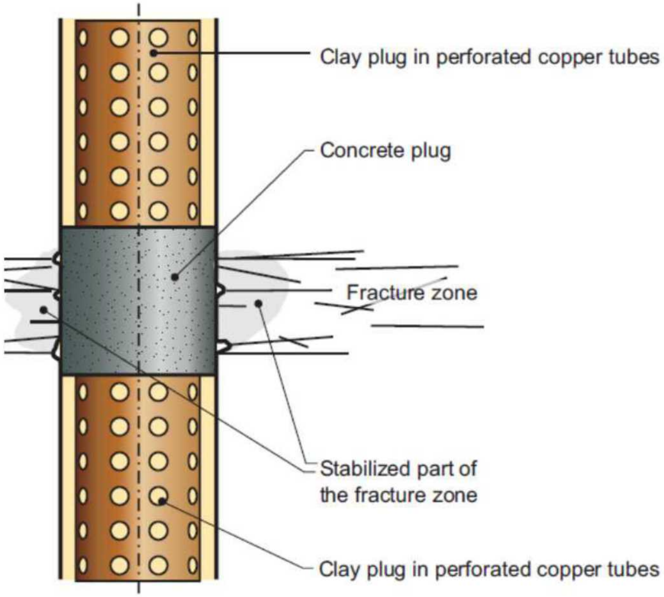
Some Remaining Conceptual Design Questions

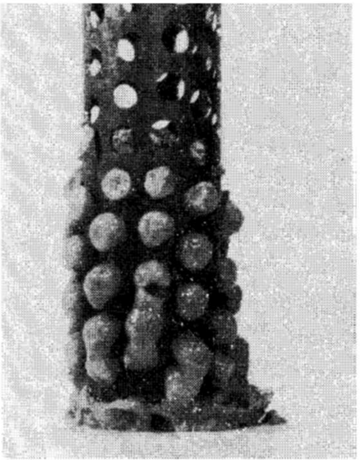
- Deep Borehole Field Test
  a) **Basement interval completion and emplacement fluid**
  b) **Factor of safety, and test package metallurgy**
  c) **Test package terminal sinking velocity**
  d) **Impact limiter design and performance**
  e) **Package release mechanism**
- Disposal System (in addition to above)
  a) **Multi-purpose cask vs. transporation + transfer casks**
  b) **Emergency equipment repairs in radiation environments**
  c) **Functional safety control (interlock) system**
  d) **Engineered measures to prevent packages getting stuck**
  e) **Waste package drop resistance (dry, surface)**

Sealing Materials and Methods General Outline

- Sealing *
  - Smectites, illites, zeolites
  - Emplacement methods
- Cement *
  - Material properties and longevity
  - Emplacement methods and setting time
- Rock Melting
  - Low permeability plug
  - Controlled annealing of host rock

Following 35+ years R&D for sealing investigation boreholes and repository shafts





Laboratory immersion 24 hr

(Pusch, R. Borehole sealing with highly compacted Na bentonite. SKB TR-81-09)