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Spent Fuel and Waste Science and Technology

Deep Borehole Disposal Conceptual Design – Preclosure Safety Analysis

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Outline

- **Objective of study**
- **Brief review of conceptual design**
  - Design bases
  - Options considered
  - Packaging
  - Emplacement method
  - Borehole completion
  - TBDs
- **Safety Assessment Methodology**
  - Part 63, Categories 1 and 2
  - Event tree PRA
  - YM (BSC) approach
- **Assumptions**
- **Initiating events**
  - Internal and external
- **Preliminary results**
  - Exposure duration
  - DBGM 1, 2A, 2B, 2C
- **Path to completion**
- **Preliminary conclusions**

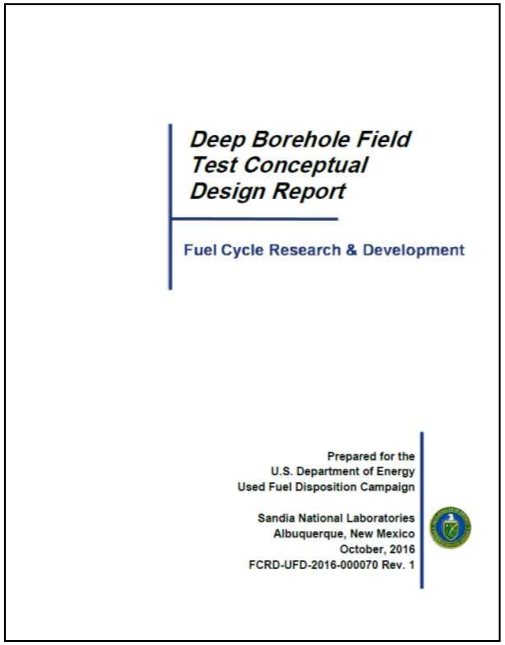
Objective for DBD Preclosure Safety Assessment

- **Identify risk factors for disposal operations, to aid design for the planned deep borehole field test (DBFT) engineering demonstration**
  - Consider actual deep borehole disposal (DBD) operations, to develop conclusions that can be applied to the DBFT demonstration
- **Challenges:**
  - Level of design detail
  - Generic (site)

Climax Spent Fuel Test
Nevada Test Site
1978 - 1983

DBFT CDR: Design Bases (*DBFT Conceptual Design Report*)

- Summary of Deep Borehole Disposal Safety Case
- Preclosure and Postclosure Conditions for Deep Borehole Disposal
- Functional and Operational Requirements for Disposal System and DBFT
- Design Assumptions for DBD and DBFT
- Waste Types
- Waste Packaging Options
- Disposal Borehole Construction Options
- Surface Handling and Transfer Options
- Emplacement Options


Deep Borehole Field Test Conceptual Design Report

Fuel Cycle Research & Development

Prepared for the
U.S. Department of Energy
Used Fuel Disposition Campaign

Sandia National Laboratories
Albuquerque, New Mexico
October, 2016
FCRD-UFD-2016-000070 Rev. 1

Conceptual Design Development: Options Considered

- **Waste Packaging Options**
  - Pressure vessels vs. waste pressurization
  - Bulk vs. pre-canistered waste forms
  - Corrosion allowance vs. corrosion resistant
- **Disposal Borehole Construction Options**
  - Diameter/Casing Plans
  - Wellhead Equipment
  - Emplacement Zone Construction
  - Sealing and Plugging
- **Surface Handling and Transfer Options**
- **Emplacement Options**
  - Drill-String Emplacement Option
  - Wireline Emplacement Option
  - Emplacement Rate Discussion
  - Coiled Tubing, Conveyance Casing, and Drop-In Options

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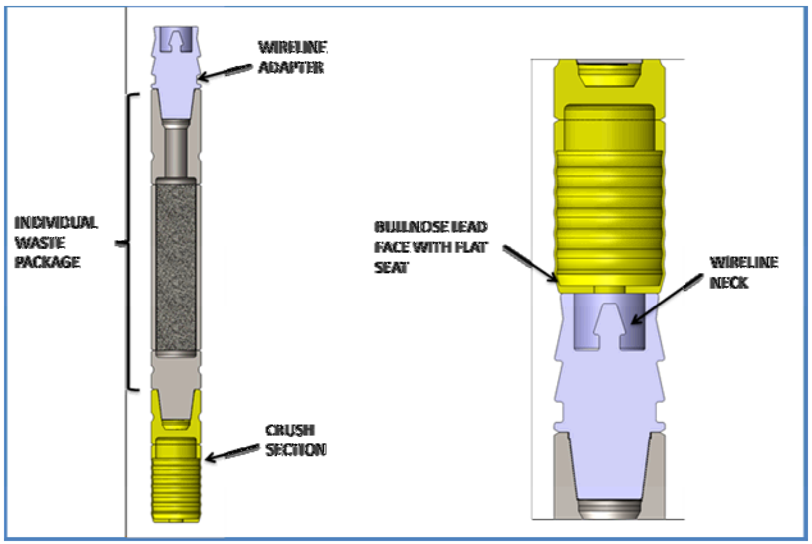
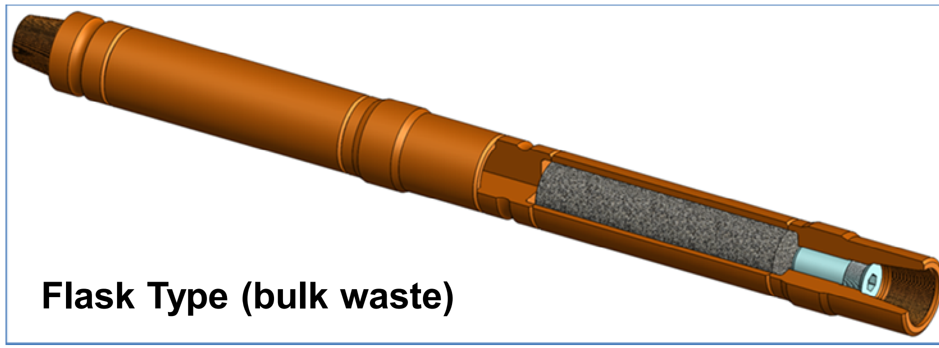
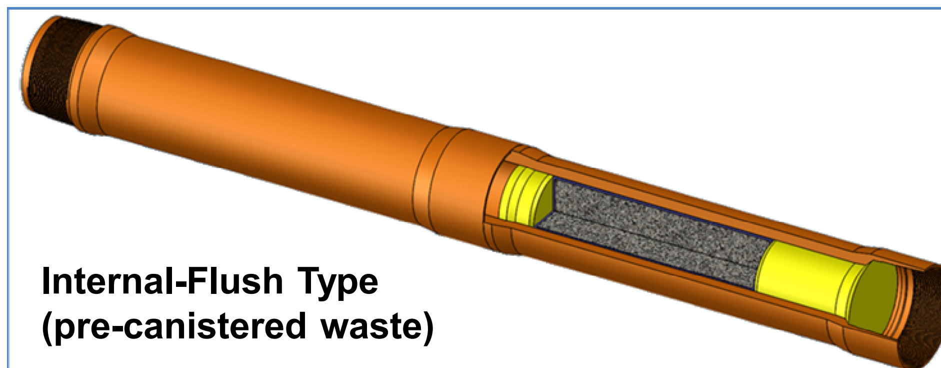
DBFT CDR: Waste Packaging

- Downhole conditions 65 MPa, 170°C, chloride brine
- Design objectives: factor of safety 2.0, containment 2 to 3 years
- Materials: medium-carbon steel (oilfield)





Flask Type (bulk waste)



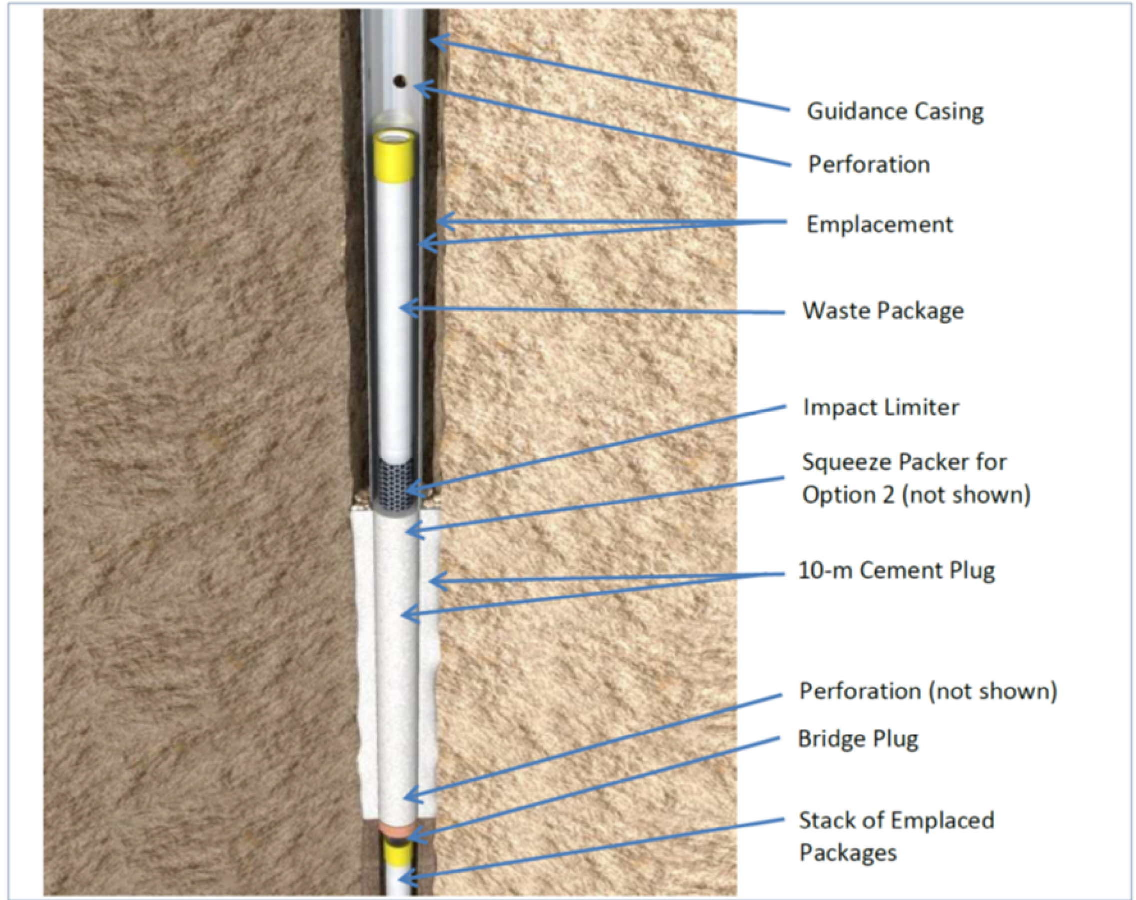
Internal-Flush Type (pre-canistered waste)

DBFT CDR: Emplacement Method

	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 CDR: Borehole Completion

- **Cemented interval plugs**
  - Stack packages in guidance casing
  - Manage load path
- **Options**
  - Pre-cemented guidance casing
  - Gravity cementing
  - Squeeze cementing
  - Fully cemented waste packages



DBFT CDR: To-Be-Determined (TBD) Items

- **50 TBDs identified; 2015 conceptual document draft reviewed by AREVA**

#	CDR Ref.	Description	Scope	Resolution Path for DBFT	Resolution Path for DBD
TBD-01	§2.3.1 §2.3.2 Table 2-3	To meet industrial safety and health requirements and radiological protection requirements for DBD activities, a broad framework would be used in design, encompassing radiological exposure and dose, nuclear criticality, QA, and so on. The particulars of such a program are beyond the scope of the DBFT, and are TBD.	DBD Only	Not applicable	Define a broader engineering development process and regulatory requirements for DBD.
TBD-02	§2.3.3 Table 2-3	Safeguards and security requirements for DBD of radioactive waste are TBD.	DBD Only	Not applicable	Develop safeguards and security requirements for DBD.
TBD-03	§2.3.4 Table 2-3	QA requirements for DBD are TBD.	All deep bore holes drilled	The UFD R&D program QA program (SNL 2014) will be used with assigned rigor level QRL 3. Data collected from the DBFT will not necessarily be used for future disposal licensing.	Develop QA requirements for DBD.
TBD-04	§2.3.5 Table 2-3	The NEPA is applicable to borehole disposal activities but specific details are TBD.	FTB and DBD	Appropriate NEPA assessment (e.g., categorical exclusion or EIS) will be determined and implemented prior to initiating field activities for the CB and FTB.	10CFR51 may be applicable, which could require an Environmental Impact Statement.
TBD-05	§2.3.5 Table 2-3	Waste disposal boreholes may be classified as injection wells in accordance with 40CFR144, but the applicability of this regulation to future DBD is TBD.	DBD Only	Not applicable	Pursue ruling on applicability of Underground Injection Control requirements to DBD.

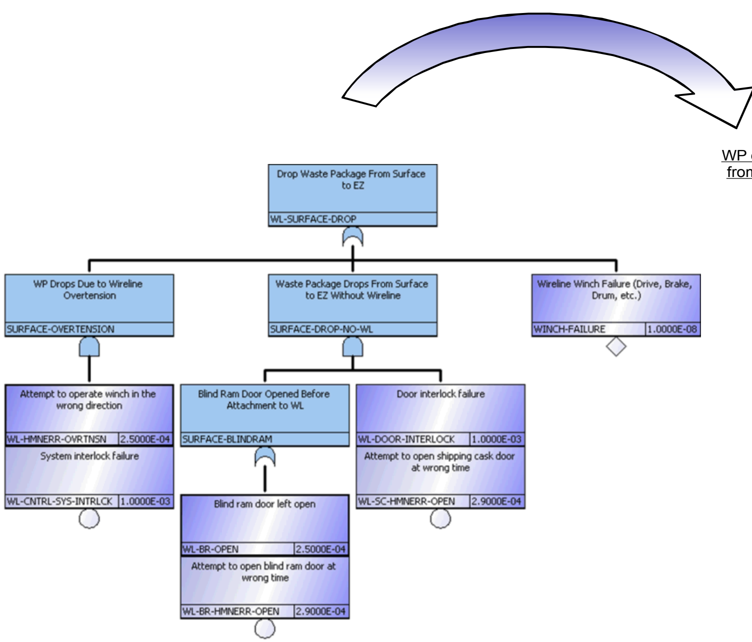
DBD Safety Assessment Methodology: 10CFR63.111 – Preclosure Performance Objectives

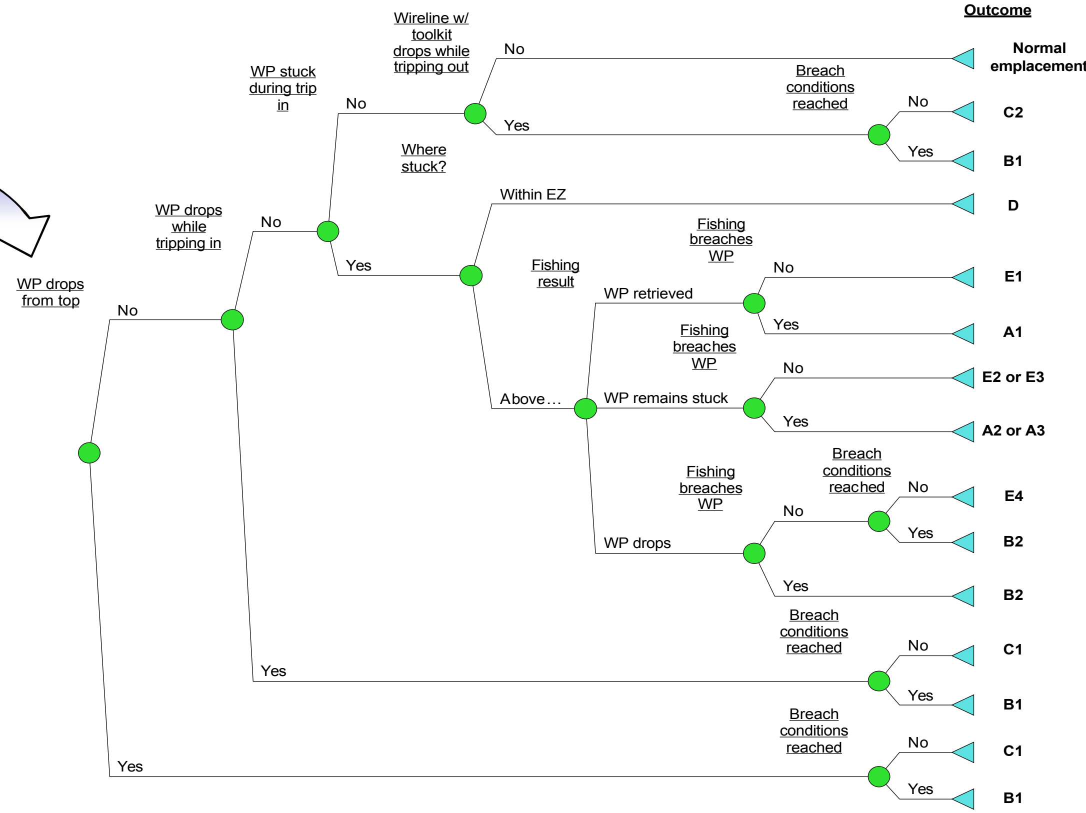
Objective	Requirement	Comments
On-Site Worker Dose	For normal operations and **Category 1** event sequences (i.e., expected at least once during operations) … limit ***aggregate*** worker doses to • Annual dose ≤ 5 rem/yr, or … • [Dose types and levels as specified]	Qualitative, category-based assessments for normal and off-normal operations
Off-Site Dose to Members of the Public	For normal operations and Category 1 event sequences, limit annual doses to ≤ 15 mrem/yr.	Off-site dose (release of radioactive material) is considered negligible for normal and off-normal DBD operations* • Except for waste package breach downhole, which requires recovery planning that is beyond the scope of this assessment.
	Limit annual dose to any member of the public in the ***general environment*** to: • ≤ 25 mrem/yr whole body, and • ≤ 75 mrem/yr thyroid, and • ≤ 25 mrem/yr any other critical organ.	
Preclosure Design Objectives	Taking into consideration a single **Category 2** event sequence (i.e., at least one chance in 10^4 of occurring before permanent closure) off-site dose is as specified above for on-site worker dose.	Addressed by conceptual design activities described in this assessment.
Objectives for the GROA	• Design and operations … must meet 10CFR20 • Preclosure safety analysis • Waste retrievability requirements • Performance confirmation	• Application of retrievability requirements to DBD is to-be-determined (SNL 2016, TBD-39).

DBD Safety Assessment Methodology: Probabilistic Risk Assessment (PRA) Background

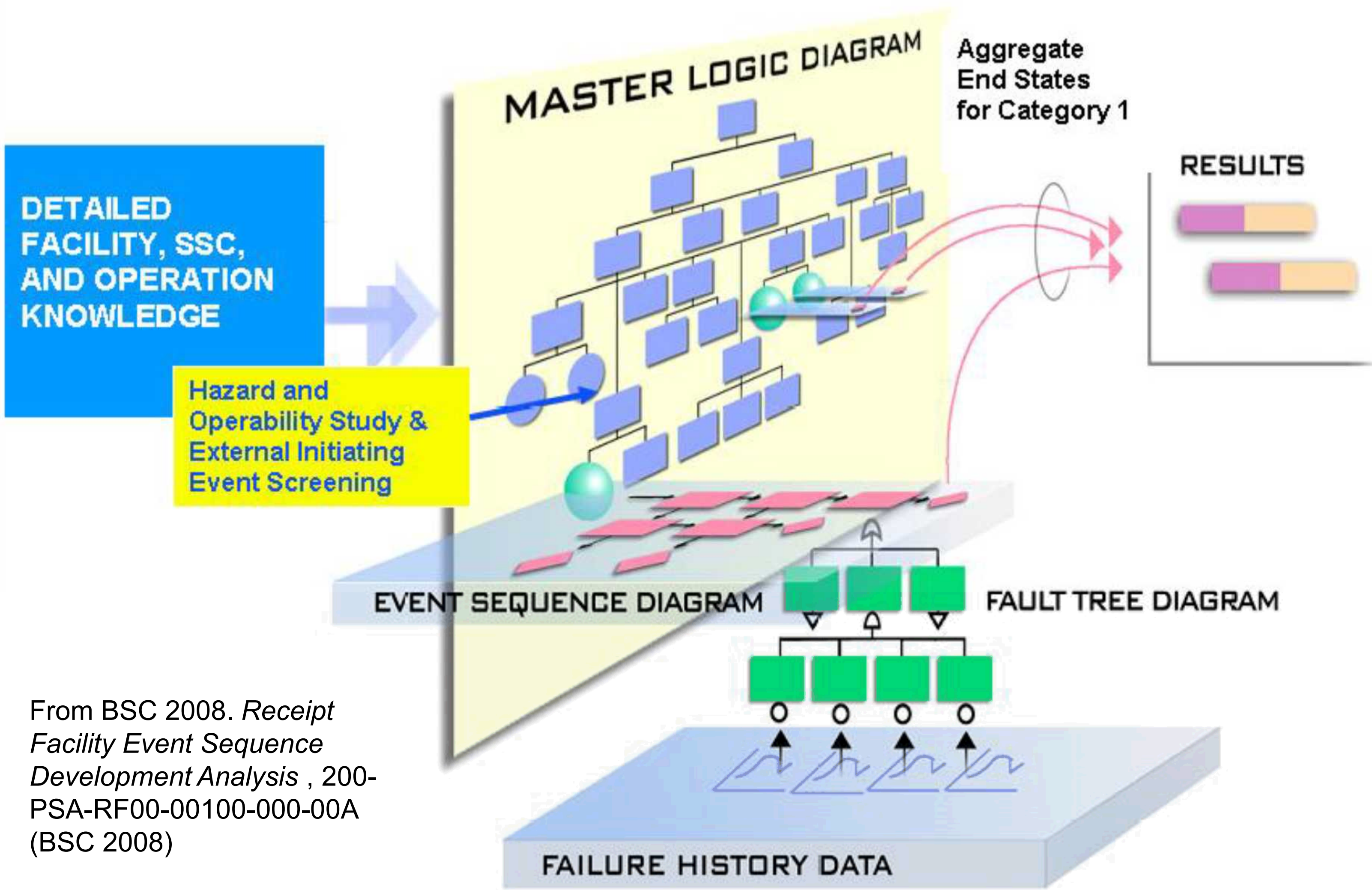
1. What can go wrong?
2. What are the consequences?
3. How likely is it?

Figures taken from the emplacement mode design selection study, *Deep Borehole Field Test Conceptual Design Report* (SNL 2016)





DBD Safety Assessment Methodology: YM License Application Preclosure Safety Assessment (PCSA) Approach



From BSC 2008. *Receipt Facility Event Sequence Development Analysis* , 200-PSA-RF00-00100-000-00A (BSC 2008)

DBD Safety Assessment Study: Assumptions (1/2)

- Scope of waste disposal activities (waste type, storage, repackaging, single- and multiple-borehole disposal campaigns
- Purpose-designed, double-ended transfer cask
- Compliance with other regulations (occupational, permitting)
- Limited use of hazardous materials
- Ease and cost of siting, construction, operation and closure (geologic, hydrologic, transportation, etc.)
- Site remoteness and control (population, industrial, military)
- Cask containment = loss of shielding; max. drop height 3 m

# Boreholes Active at a Time	Duration of Phase (yr)	Total # Boreholes in Phase
1	6	3
3	10	15
5	32	80
2	2	2

DBD Safety Assessment Study: Assumptions (2/2)

- **Internal events**
  - Internal flooding not credible
  - Internal fire suppression
  - Safe shutdown of all systems and components (SSCs, on the surface)
  - Off-normal recovery actions are beyond scope of study
- **External events**
  - External flooding prevented by site engineering
  - External fire standoff distance, suppression
  - Category 1 seismic event: 0.16 g (2,500 yr recurrence)
  - Category 2 seismic event: ≤ 0.5 g (500,000 yr recurrence)*
  - Fault offset hazard negligible (away from capable faults)
  - Other geologic hazards (e.g., landslide, karst collapse, volcanism) negligible
  - Aircraft crash hazard negligible
  - Extraterrestrial hazards negligible
  - SSCs do not require off-site power or central cooling
  - Extreme weather hazard (e.g., lightning) mitigated by procedural controls

DBD Safety Assessment Study: Internal Initiating Events Considered

- Cask movement (drop cask, drop object on cask, cask collision, unplanned movement, incorrect placement or rigging, shield plug dislodges, *work platform collapses*)
- Cask-to-cask transfer (misalignment, stuck, loss of shielding, incorrect operation)
- Transfer cask operation (latch failure)
- Wellhead setup (cask misplacement, carousel failure, kneeling jack failure, unplanned movement, cask toppling, shield plug removal failure, wellhead equipment failure)
- Wireline operation (tool misassembly, package latch failure, hoist failure, instrumentation failure, cable damage, debris in hole, casing collapse, package stuck, package drops, package breached in hole, wireline drops on trip out, pressure “kick”)
- General (flooding, fire, electrical, excess temperature, loss of power)

Italics = excluded in hazard analysis

DBD Safety Assessment Study: External Initiating Events Considered

Italics = excluded in hazard analysis

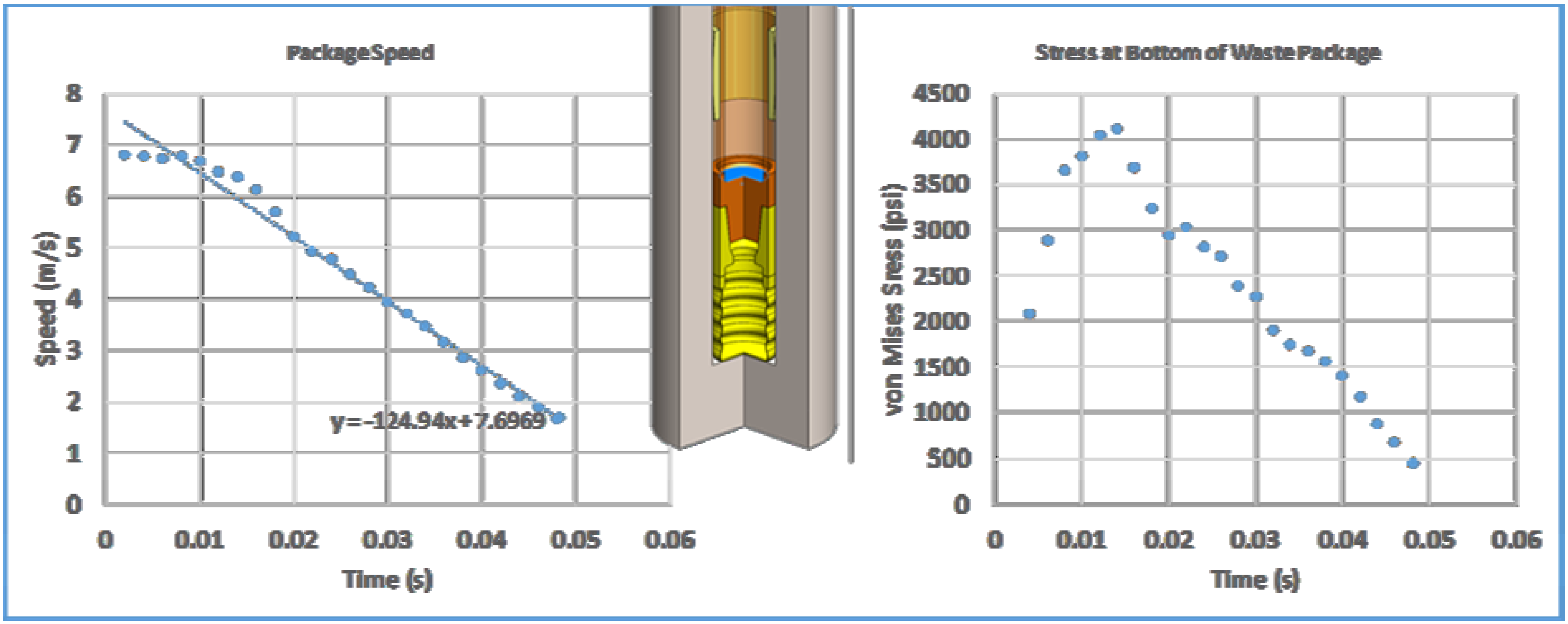
- **Seismic ground motion**
- ***Tectonic faulting***
- ***Non-seismic geologic events (incl. volcanic activity)***
- ***Extreme weather (high winds, tornadoes, hurricanes, lightning)***
- ***External floods***
- ***Loss of power***
- ***Loss of cooling capability***
- ***Aircraft crash***
- ***Nearby industrial/military accidents (incl. transportation)***
- ***Onsite hazardous materials release***
- ***External fire***
- ***Extraterrestrial activity (meteorites, falling satellites)***

DBD Safety Assessment Study: Preliminary Results (1/3)

- **Cask drop risk possibly most significant at the surface**
  - Simulations vs. prior art
- ***Partial* risk mitigation could be achieved with a new double-ended, multipurpose cask design (combine transport and transfer)**
- **Conceptual design challenges:**
  - Transfer station design (sliding shield, cradles)
  - Wellhead station design (palte & carousel, lower plug removal hardware, wellhead flange interface)
  - Tiedowns (seismic) for transfer cask mounted on carousel
  - Functional safety (interlocks) system

DBD Safety Assessment Study: Preliminary Results (1/3)

- **Dynamic finite element simulation (SolidWorks) of conceptual waste package within a transport cask (NAC LWT description)**
- **Stress/strain behavior in waste package containment envelope << yield**



Simulation results for vertical end-drop from 3 m onto compacted gravel.

DBD Safety Assessment Study: Preliminary Results (2/3)

Exposure duration effects

The additional probabilistic safety margin represented by fractional exposure duration, is used to calculate a new level of concern for seismic ground motion at the Category 2 probability level (10^{-4} probability over the 50-year duration of a large-scale disposal campaign). The calculation follows

$$p' = 10^{-4}/(N \times D)$$

where

p'	=	Probability level of concern (yr^{-1}) for seismic events (reciprocal for recurrence)
10^{-4}	=	Category 2 threshold probability for event sequences (per 50-year campaign)
N	=	Number of waste packages (30,000 per 50-year campaign)
D	=	Exposure duration (yr) per waste package

Because of exposure duration:

- Surface handling SSCs can be designed to withstand weaker ground motion (~10^5 year recurrence, DBGM-2A)
- SSCs used in downhole activities should withstand stronger ground motion (~2×10^5 year recurrence, DBGM-2B)

DBD Safety Assessment Study: Preliminary Results (3/3)

- **Supporting equipment should withstand strongest ground motion (~5×10^5 year recurrence, DBGM-2C)**
  - Mobile crane
  - Headframe structure and hoisting functions
  - Wireline system
  - Power supply (on-site or off-site)
  - Control/functional safety system
- **Design strategy**
  - Prevent waste package breach
  - Safe shutdown of active processes
  - Recovery

DBD Safety Assessment Study: Path to Completion (FY17)

- Review and make final changes to internal initiating "top events" and failed states (ESDs)
- Screen initial events (credibility, likelihood, design impact)
- Construct fault trees for ~50 "top events" (relate human error, functional safety, equipment malfunction)
- Develop consequence end-state categories
- Build model in SAPHIRE
- Calculate end-state probabilities
- Sensitivity analyses (e.g., cask drop fragility, hazard convolution)
- M2 report (Sept 2017)

DBD Safety Assessment Study: Preliminary Conclusions

- **Radionuclide release from cask drop events may be non-credible**
- **Single-borehole disposal campaign would be significantly less challenging to achieve required safety**
  - Category 1 items essentially the same
  - Category 2 event frequency decreased 100X
- **Structure of DBD activities allows parsing of Category 2 events (similar to YM PCSA)**
- **Design insights abound**
- **Functional safety will be needed to prevent/mitigate Category 1 events**