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Steps to Sharing

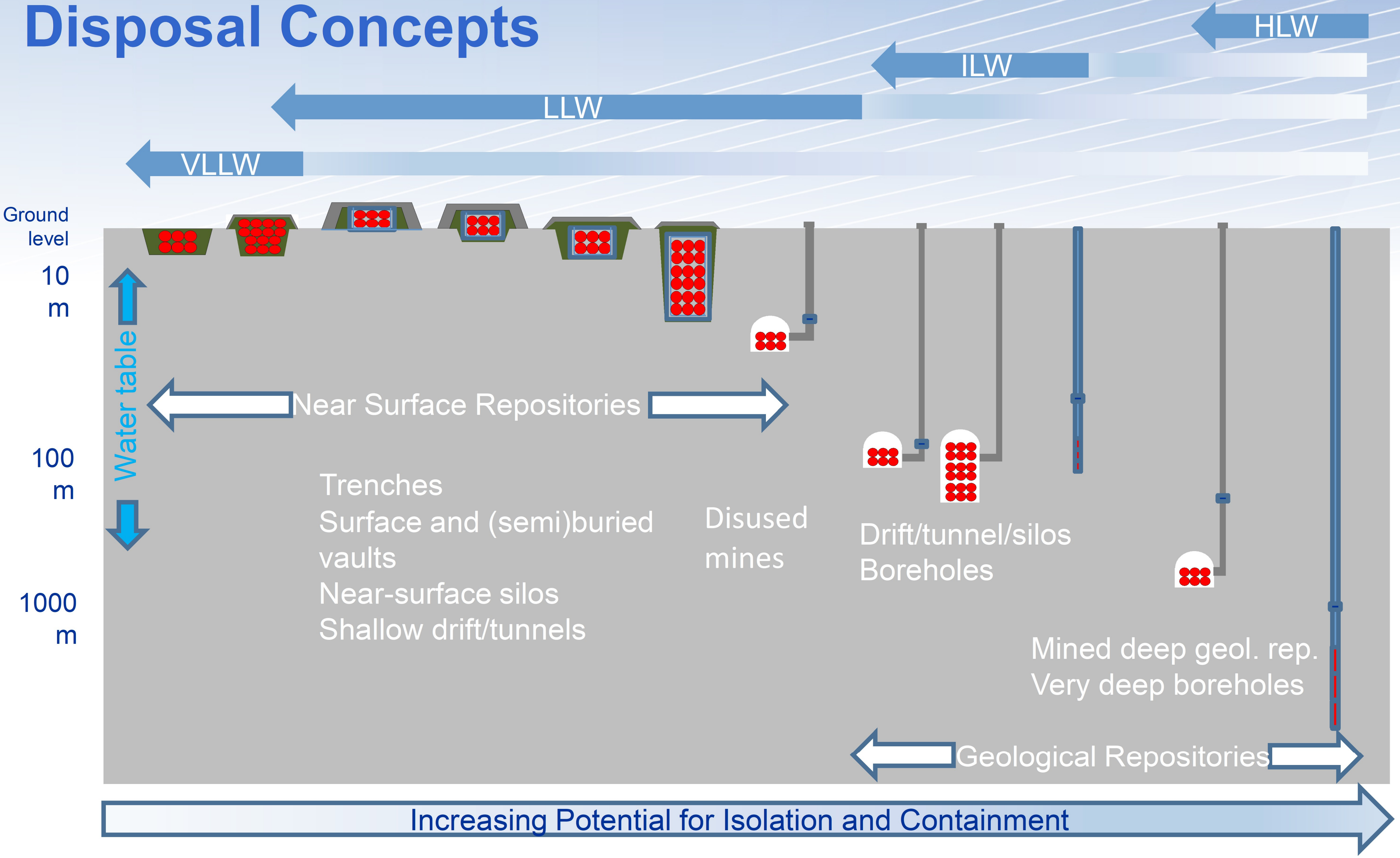
25th – 26th September 2019, IAEA, Vienna

Deep Borehole Disposal

Neil Chapman

ERDO-WG and Arius Association

Disposal Concepts



HLW
ILW
LLW
VLLW

Ground level
10 m
100 m
1000 m
Water table

Near Surface Repositories

Trenches
Surface and (semi)buried vaults
Near-surface silos
Shallow drift/tunnels

Disused mines

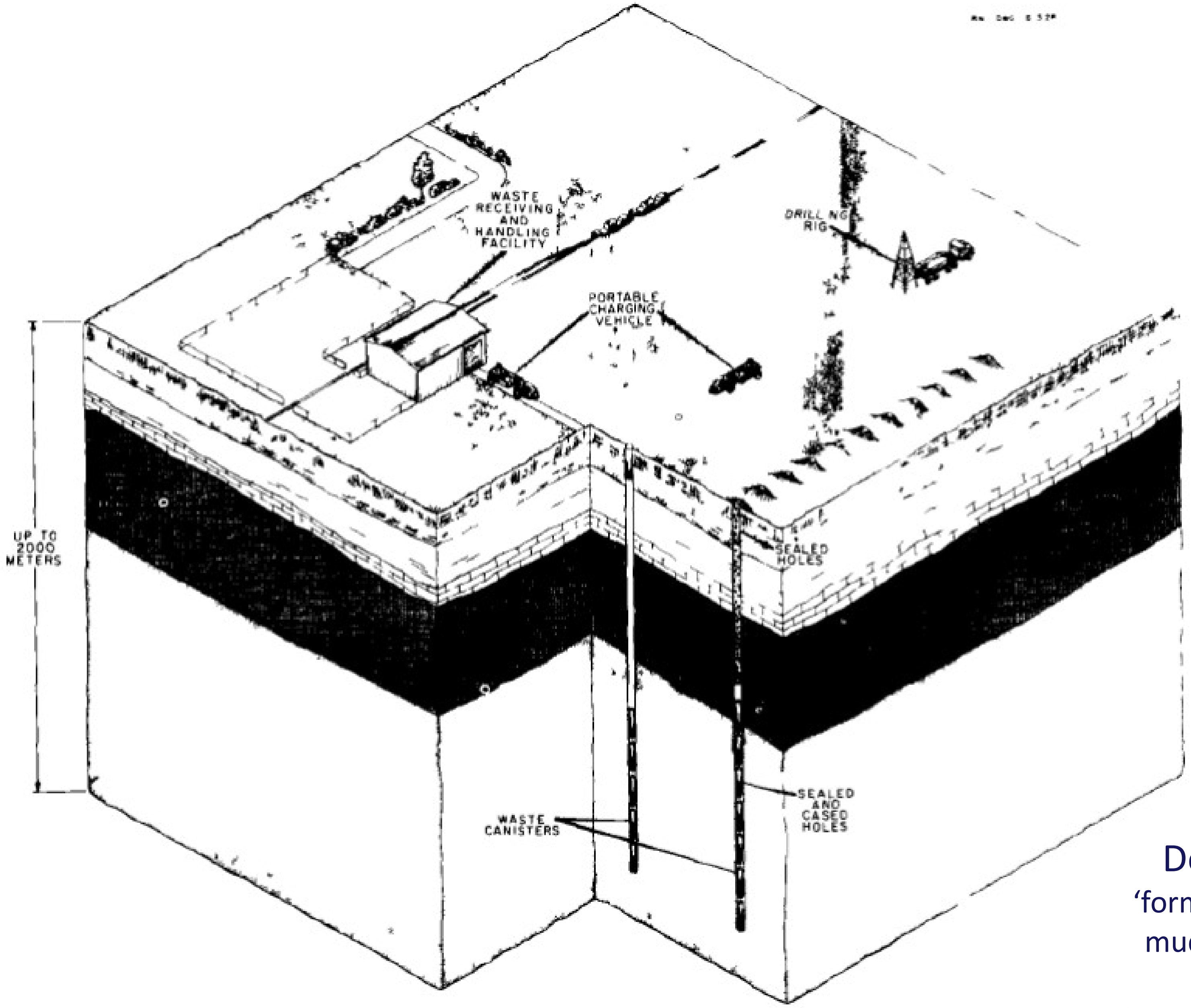
Drift/tunnel/silos
Boreholes

Mined deep geol. rep.
Very deep boreholes

Geological Repositories

Increasing Potential for Isolation and Containment

1976



40 years ago….

‘Superdeep’
10 – 20 km
‘engineering doubtful’
‘not viable’

☐

Rock melting
…many pages!

☐

Deep matrix 1 m holes
‘formidable problems’ (plugging, mud disposal, K enhancement)

‘enough merit’ for feasibility study

☐

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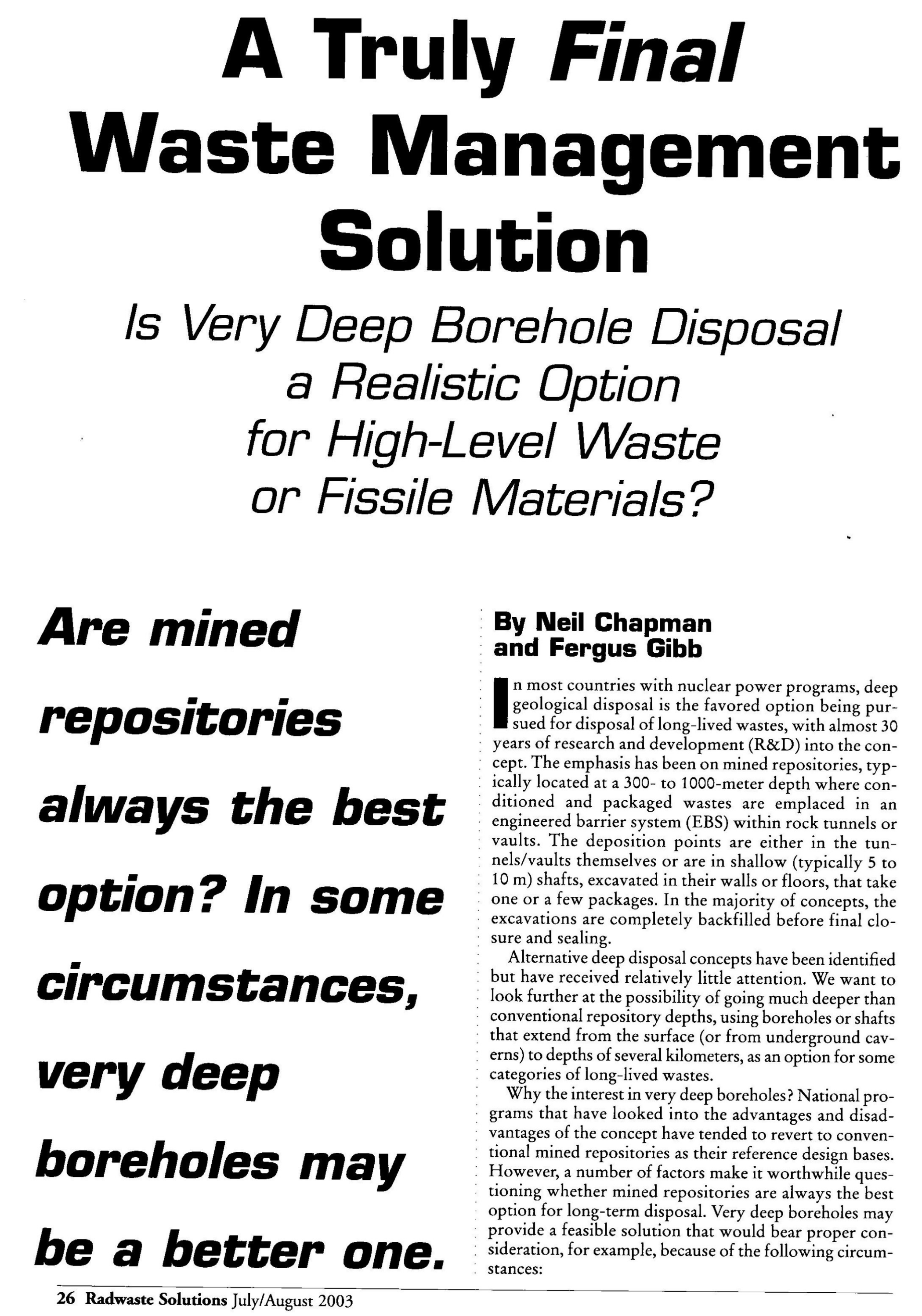
1976 Battelle report for ERDA: deep borehole matrix



A Truly *Final* Waste Management Solution

Is Very Deep Borehole Disposal a Realistic Option for High-Level Waste or Fissile Materials?

Are mined repositories always the best option? In some circumstances, very deep boreholes may be a better one.

By Neil Chapman
and Fergus Gibb

In most countries with nuclear power programs, deep geological disposal is the favored option being pursued for disposal of long-lived wastes, with almost 30 years of research and development (R&D) into the concept. The emphasis has been on mined repositories, typically located at a 300- to 1000-meter depth where conditioned and packaged wastes are emplaced in an engineered barrier system (EBS) within rock tunnels or vaults. The deposition points are either in the tunnels/vaults themselves or are in shallow (typically 5 to 10 m) shafts, excavated in their walls or floors, that take one or a few packages. In the majority of concepts, the excavations are completely backfilled before final closure and sealing.

Alternative deep disposal concepts have been identified but have received relatively little attention. We want to look further at the possibility of going much deeper than conventional repository depths, using boreholes or shafts that extend from the surface (or from underground caverns) to depths of several kilometers, as an option for some categories of long-lived wastes.

Why the interest in very deep boreholes? National programs that have looked into the advantages and disadvantages of the concept have tended to revert to conventional mined repositories as their reference design bases. However, a number of factors make it worthwhile questioning whether mined repositories are always the best option for long-term disposal. Very deep boreholes may provide a feasible solution that would bear proper consideration, for example, because of the following circumstances:

26 **Radwaste Solutions** July/August 2003

2003

- ‘truly final’ because wastes are essentially irretrievable
- …so, suited principally for fissile materials
- …and possibly for programmes with only small HLW arisings
- if DBD’s greater isolation can’t be communicated, lack of retrievability could be a problem

USDOE
SNL
studies

2011 - date

Deep Borehole Disposal Research: Geological Data Evaluation, Alternative Waste Forms, and Borehole Seals

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Used Fuel Disposition Campaign
Bill W. Arnold, Patrick Brady,
Mark Sutton, Karl Travis
Robert MacKinnon, Fergus Gibb, and
Harris Greenberg
Sandia National Laboratories
September 5, 2014
FCRD-USED-2014-000332
SAND2014-17430 R

Deep Borehole Field Test Conceptual Design Report

Fuel Cycle Research & Development

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of Energy
Campaign

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w Mexico
ber, 2016
70 Rev. 1

SANDIA REPORT
SAND2016-3312
Unlimited Release
Printed April 2016

Large Diameter Deep Borehole (LDDB) Disposal Design Option for Vitrified High-Level Waste (HLW) and Granular Wastes

Mark J. Rigali, Steven Pye, and Ernest L. Hardin

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185-0747

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Approved for public release; further dissemination unlimited.

Sandia National Laboratories

Deep Borehole Disposal Safety Analysis

Fuel Cycle Research & Development

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

Prepared by
Geoff Freeze, Emily Stein, Laura Price,
Robert MacKinnon, and Jack Tillman
Sandia National Laboratories

September 2016
FCRD-UFD-2016-000075, Rev. 0
SAND2016-10949R

Status of DBD today

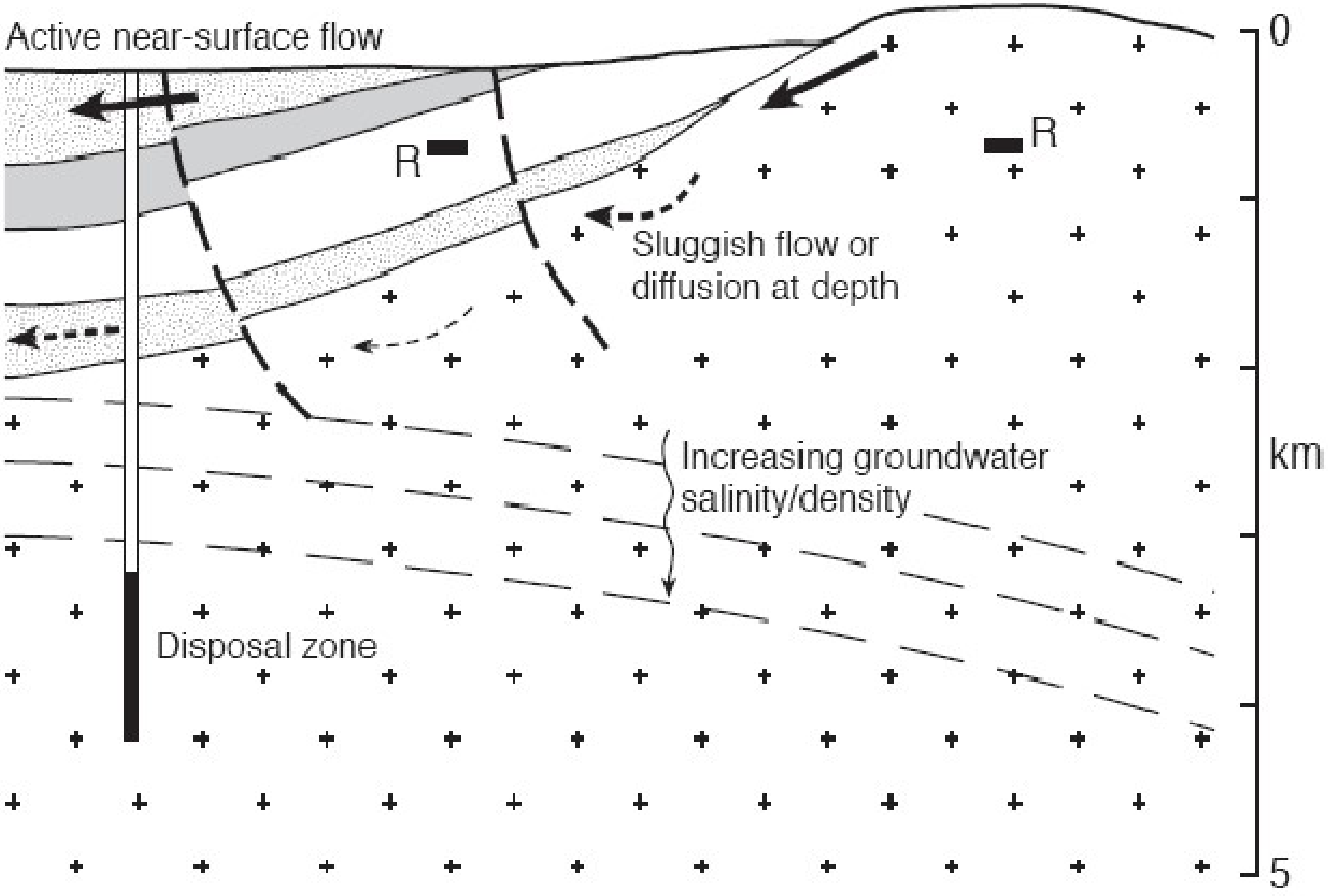
- Side-lined as an alternative for HLW/SF: 1990 until 2010
  - evaluations by SKB, Nirex etc
  - limited academic work (Sheffield)
- 2010-2017: Surge in interest in USA as Yucca Mountain faltered
  - dominated R&D and investment (DOE-SNL)
  - proposed field test cancelled
- Commercial interest in USA: 2017 to date
  - patents generated by Deep Disposal Inc
- Borehole disposal of DSRSs at intermediate depth (100-200 m) slowly coming to implementation, supported by IAEA
- 2019: New IAEA Co-ordinated Research Programme on borehole disposal
  - developing consistent, comprehensive set of guidance documents on DSRS borehole disposal
  - exploring if concept can be applied for small quantities of wastes other than DSRS
- 2019: CSIRO (Australia) proposing a field trial for reprocessing waste from research reactor spent fuel

Deep Borehole Disposal

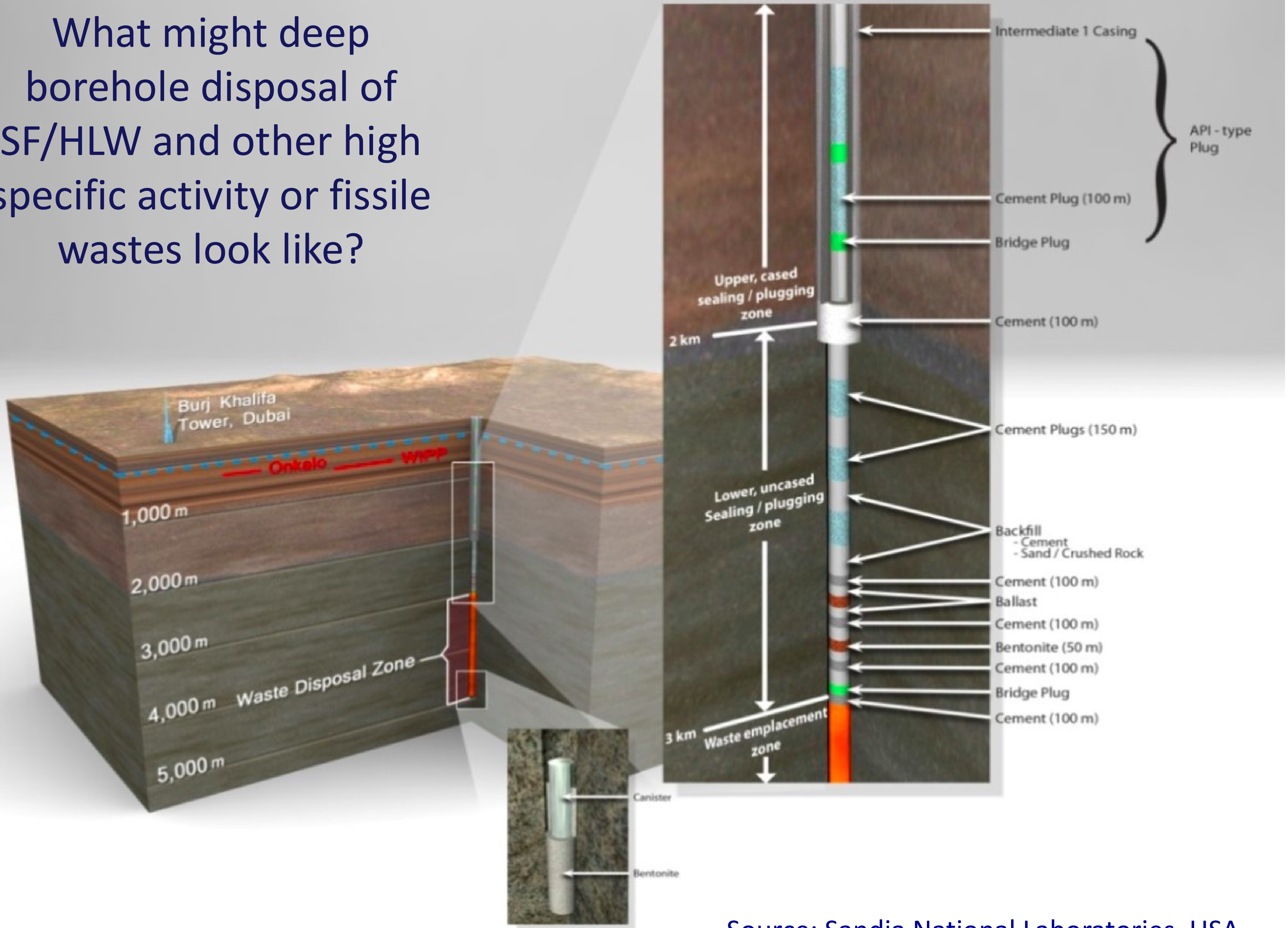
...high levels of intrinsic containment and isolation

...but limited progress beyond conceptual stage

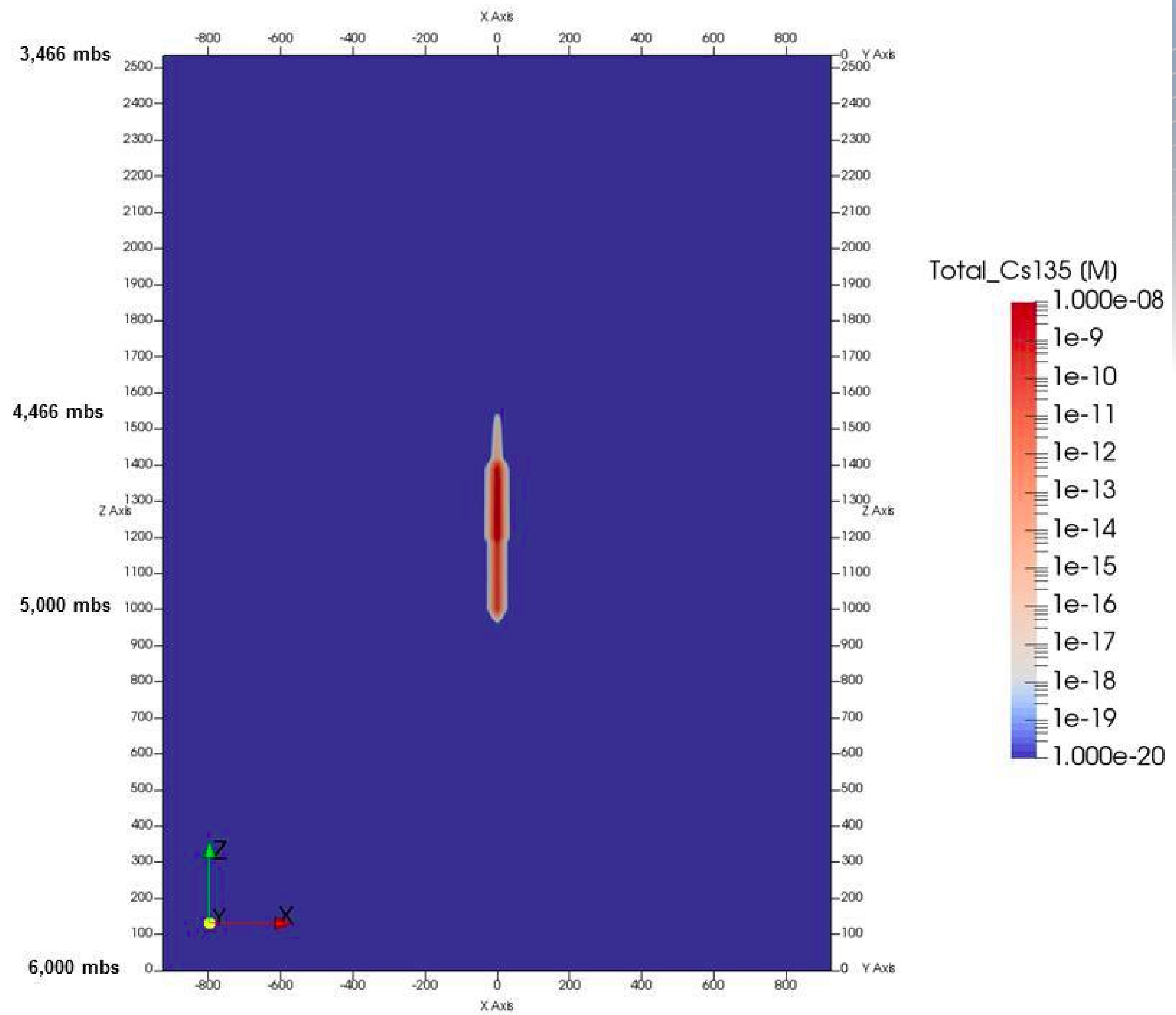
Undynamic, low to zero flow; dense, stagnant porewaters



What might deep borehole disposal of SF/HLW and other high specific activity or fissile wastes look like?



Source: Sandia National Laboratories, USA



Post-Closure Safety

Cs-135 at 10 million years

25 m up the seal zone

20 m into rock

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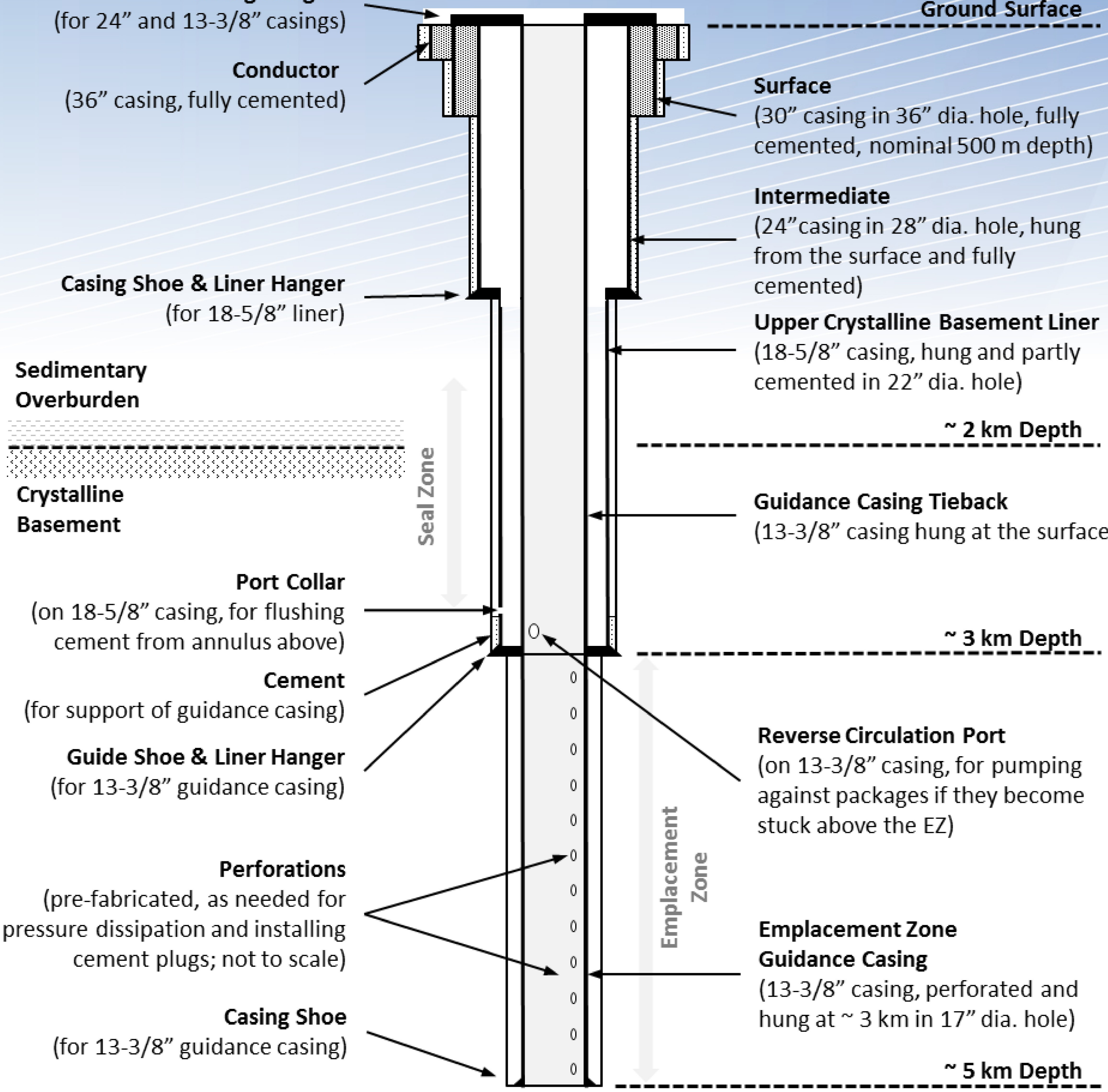
Source: Sandia National Laboratories, USA

Casing concept



Casing Hangers
(for 24" and 13-3/8" casings)

Conductor
(36" casing, fully cemented)

Casing Shoe & Liner Hanger
(for 18-5/8" liner)

Sedimentary Overburden

Crystalline Basement

Port Collar
(on 18-5/8" casing, for flushing cement from annulus above)

Cement
(for support of guidance casing)

Guide Shoe & Liner Hanger
(for 13-3/8" guidance casing)

Perforations
(pre-fabricated, as needed for pressure dissipation and installing cement plugs; not to scale)

Casing Shoe
(for 13-3/8" guidance casing)

Ground Surface

Surface
(30" casing in 36" dia. hole, fully cemented, nominal 500 m depth)

Intermediate
(24" casing in 28" dia. hole, hung from the surface and fully cemented)

Upper Crystalline Basement Liner
(18-5/8" casing, hung and partly cemented in 22" dia. hole)

~ 2 km Depth

Guidance Casing Tieback
(13-3/8" casing hung at the surface)

~ 3 km Depth

Reverse Circulation Port
(on 13-3/8" casing, for pumping against packages if they become stuck above the EZ)

Emplacement Zone Guidance Casing
(13-3/8" casing, perforated and hung at ~ 3 km in 17" dia. hole)

~ 5 km Depth

Source: Sandia National Laboratories, USA

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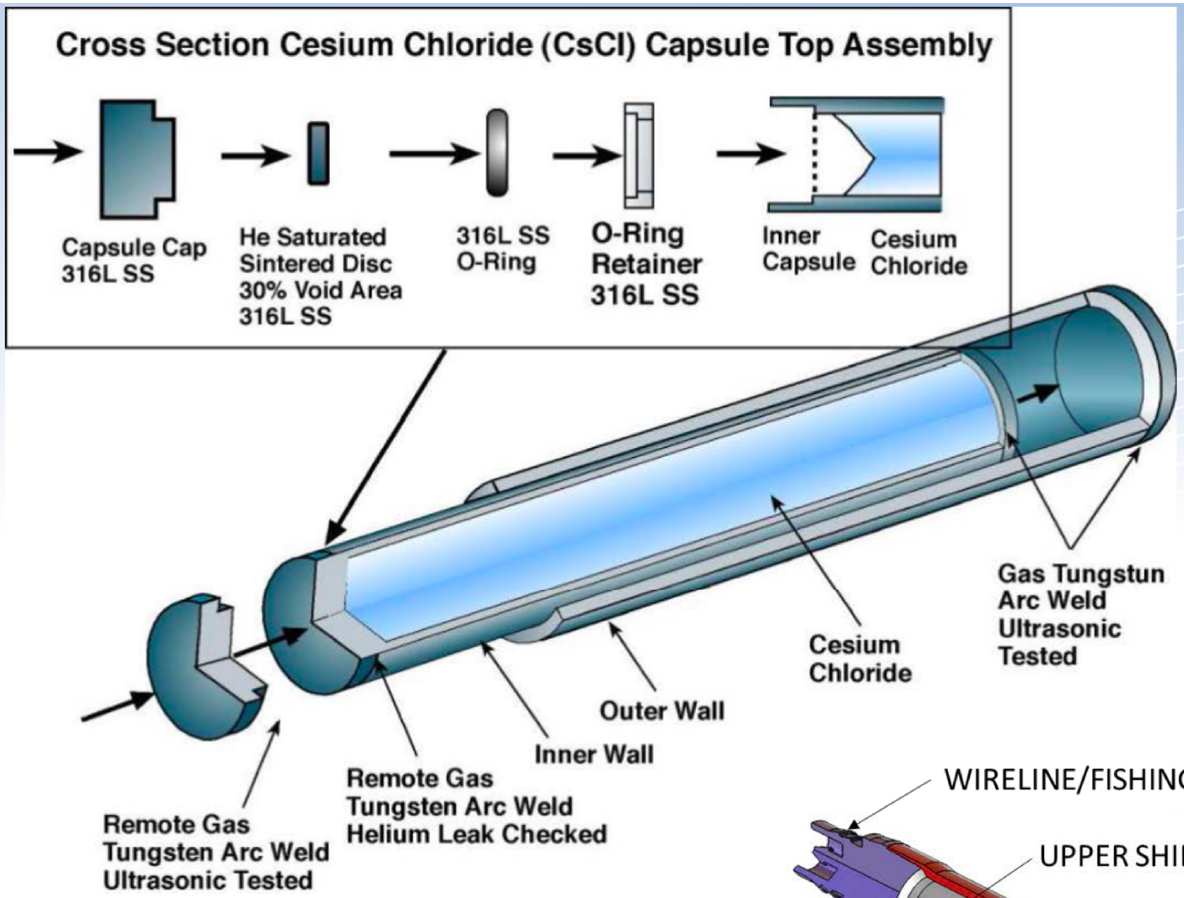
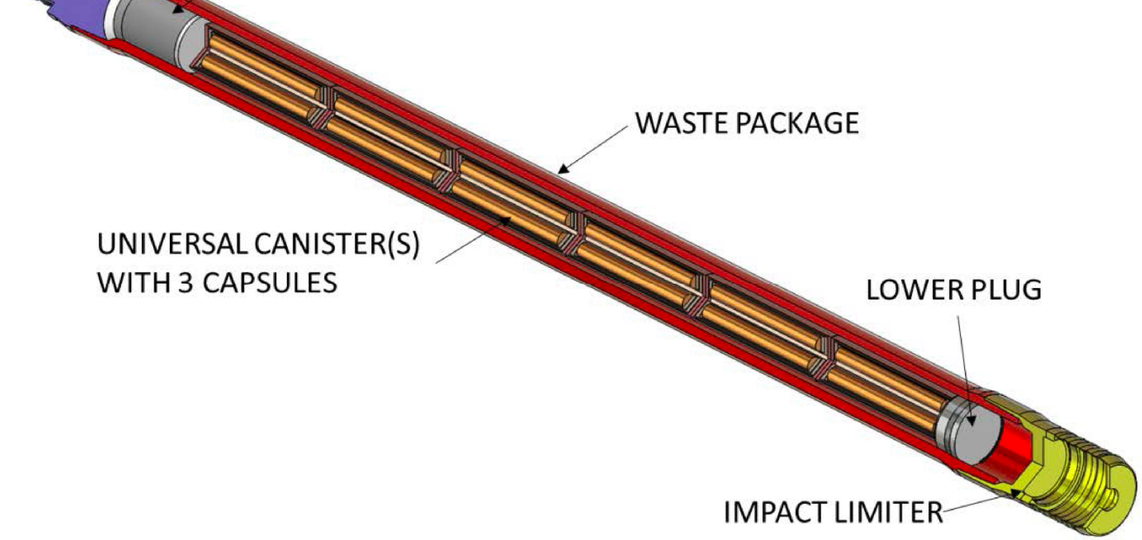
Field test of concept for disposal of Hanford separated Cs and Sr capsules





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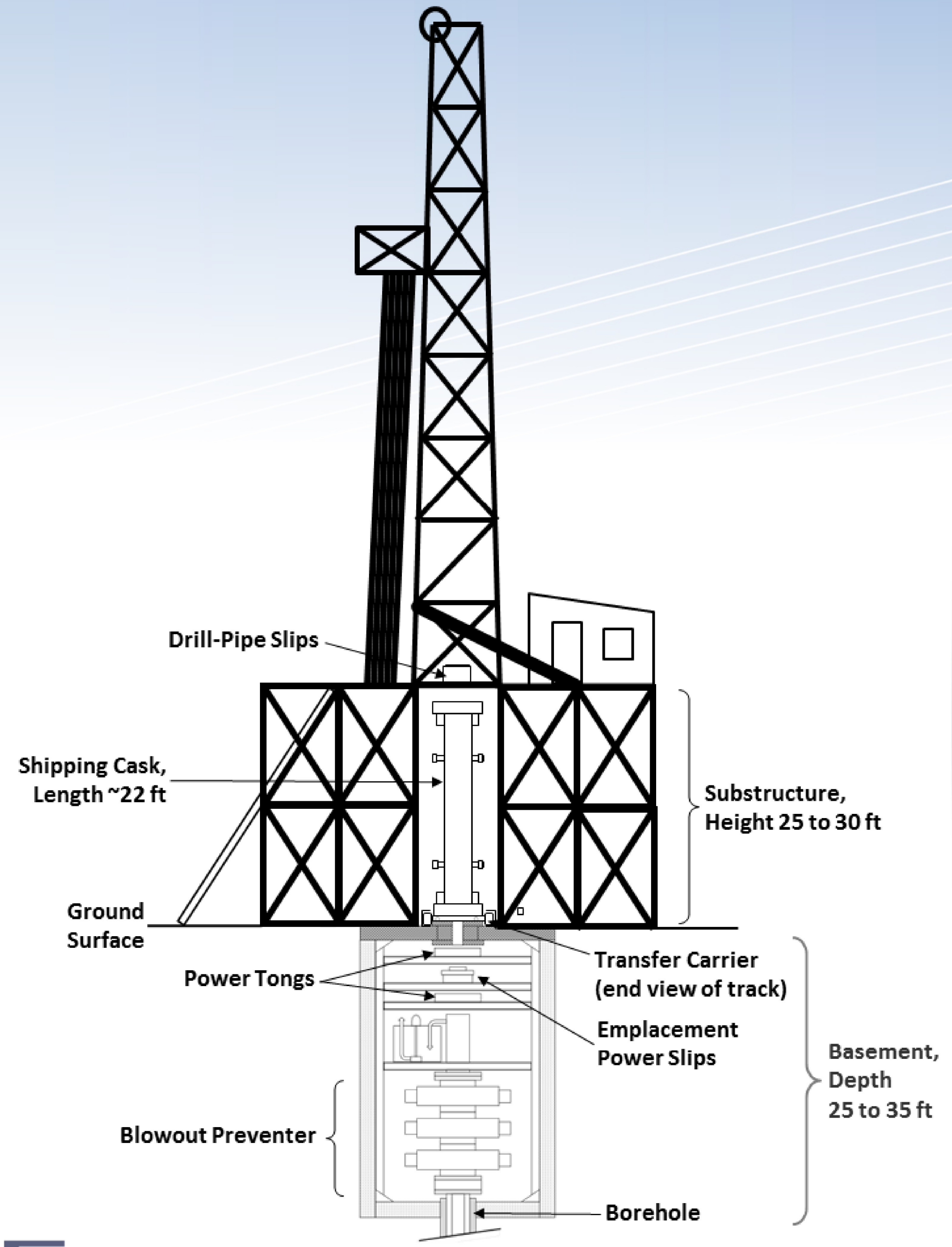
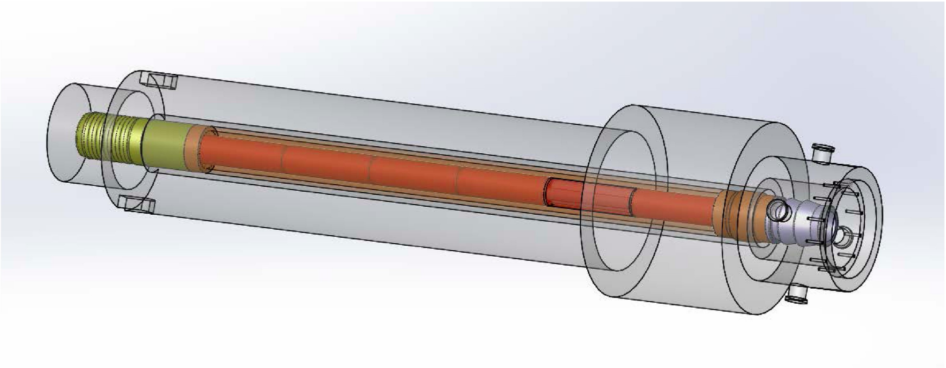
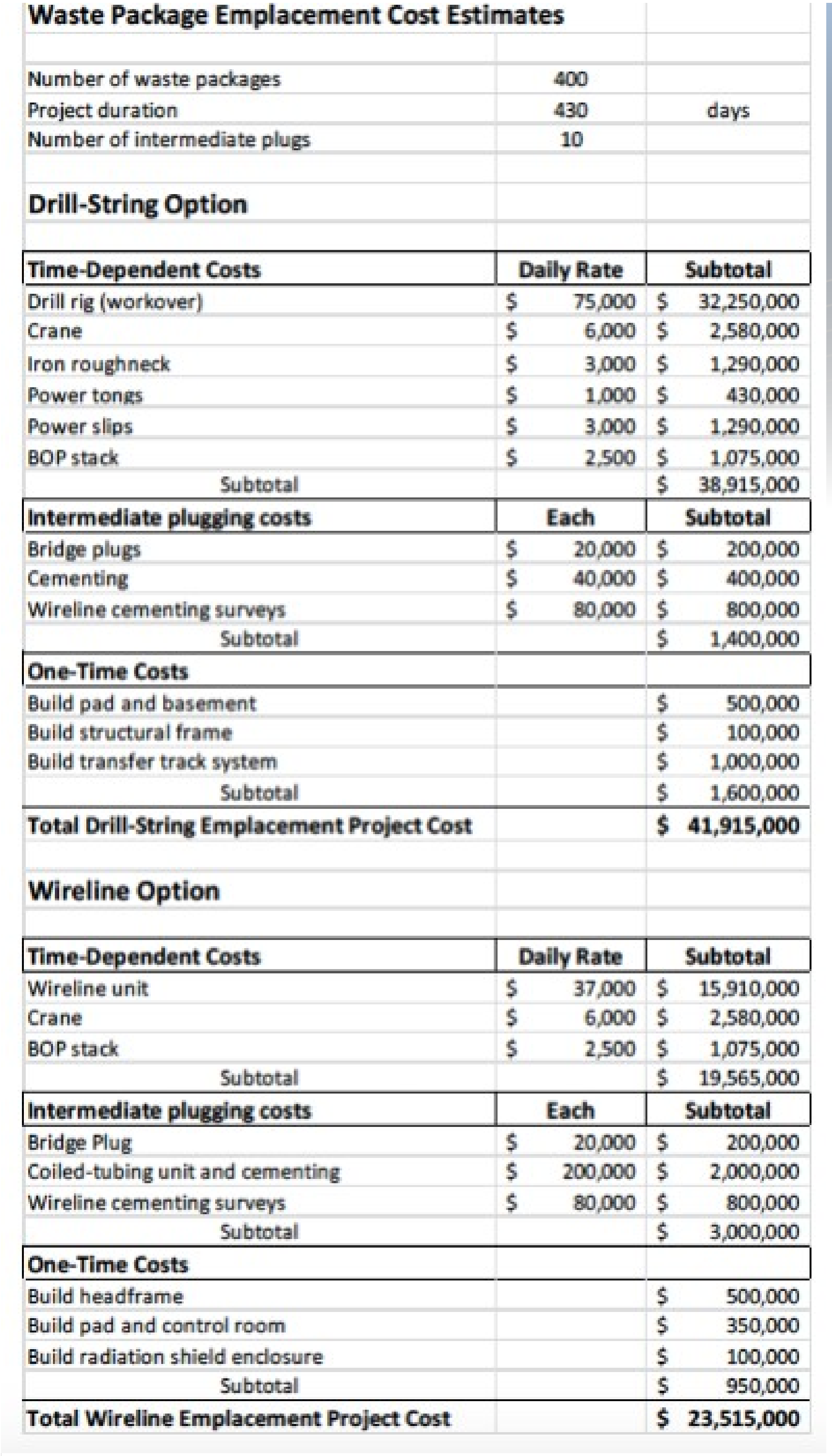
Source: Sandia National Laboratories, USA

DBD Field test: emplacement option





Source: Sandia National Laboratories, USA



Waste Package Emplacement Cost Estimates

Number of waste packages	400	
Project duration	430	days
Number of intermediate plugs	10	

Drill-String Option

Time-Dependent Costs	Daily Rate	Subtotal
Drill rig (workover)	$ 75,000	$ 32,250,000
Crane	$ 6,000	$ 2,580,000
Iron roughneck	$ 3,000	$ 1,290,000
Power tongs	$ 1,000	$ 430,000
Power slips	$ 3,000	$ 1,290,000
BOP stack	$ 2,500	$ 1,075,000
Subtotal		$ 38,915,000
Intermediate plugging costs	**Each**	**Subtotal**
Bridge plugs	$ 20,000	$ 200,000
Cementing	$ 40,000	$ 400,000
Wireline cementing surveys	$ 80,000	$ 800,000
Subtotal		$ 1,400,000
One-Time Costs		
Build pad and basement		$ 500,000
Build structural frame		$ 100,000
Build transfer track system		$ 1,000,000
Subtotal		$ 1,600,000
Total Drill-String Emplacement Project Cost		**$ 41,915,000**

Wireline Option

Time-Dependent Costs	Daily Rate	Subtotal
Wireline unit	$ 37,000	$ 15,910,000
Crane	$ 6,000	$ 2,580,000
BOP stack	$ 2,500	$ 1,075,000
Subtotal		$ 19,565,000
Intermediate plugging costs	**Each**	**Subtotal**
Bridge Plug	$ 20,000	$ 200,000
Coiled-tubing unit and cementing	$ 200,000	$ 2,000,000
Wireline cementing surveys	$ 80,000	$ 800,000
Subtotal		$ 3,000,000
One-Time Costs		
Build headframe		$ 500,000
Build pad and control room		$ 350,000
Build radiation shield enclosure		$ 100,000
Subtotal		$ 950,000
Total Wireline Emplacement Project Cost		**$ 23,515,000**

Cost estimate for DBD field test

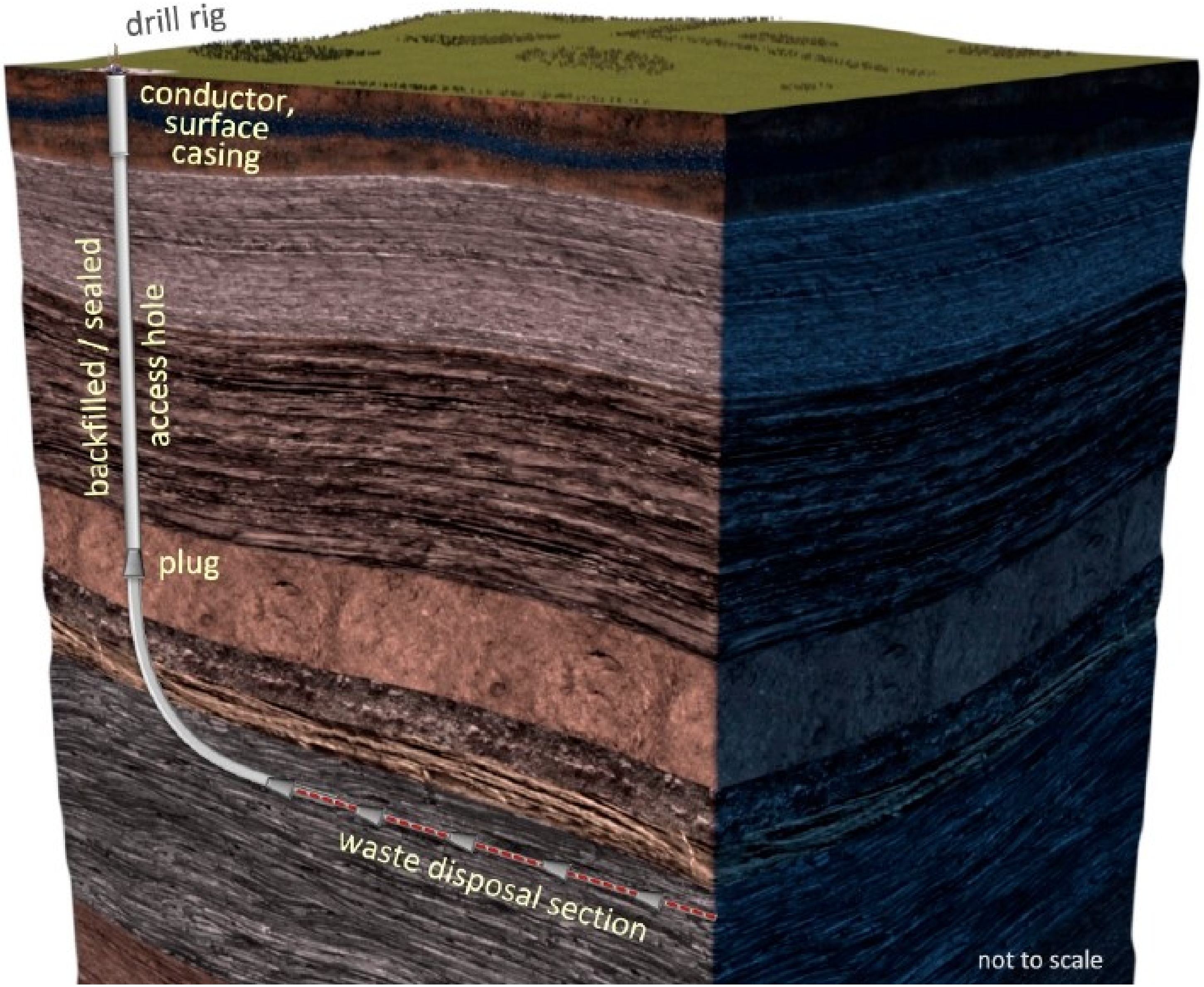
Off-normal scenario costs pushed these figures up to c.50 to 300 MUSD

Several other borehole cost estimates over last 10 years: they vary considerably

More reliable estimates would likely place a 2 – 3km hole at around 10 - 20 MUSD

…to which, add siting, packaging, operations etc

Source: Sandia National Laboratories, USA



Deep Isolation Inc.

Commercial venture, evaluating sub-horizontal disposal of SF in deviated boreholes at around 1000 m depth based on adapted oil-field technologies

Applicability of DBD to Member States with Small Inventories

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What wastes is DBD suitable for?

Technical attribute	*Comments*
Attributes making a waste type potentially suitable for DBD	
High concentration of long-lived radionuclides	*Would motivate a solution that guarantees a high degree of isolation for a very long period (millions of years)*
High specific activity	*For example, very high specific activity wastes, even though they contain only short-lived radionuclides*
Small total volume	*Only a few tens to hundreds of cubic metres: volumes of thousands of cubic metres would require several to many boreholes*
Small package size	*Maximum diameters of useable borehole space at several kilometres depth are around 400 to 500 mm*
Separated fissile material	*Nuclear safeguards requirements would motivate guaranteed total isolation with no real prospect of retrieval and misuse*
Attributes making a waste type potentially unsuitable for DBD	
Large total volume	*Would require many boreholes, which could challenge economics and practicality*
Large package size	*Would not fit in a borehole: dismantling or reconditioning to smaller packages might be impractical or give rise to operator doses that are unnecessary if an alternative solution exists*

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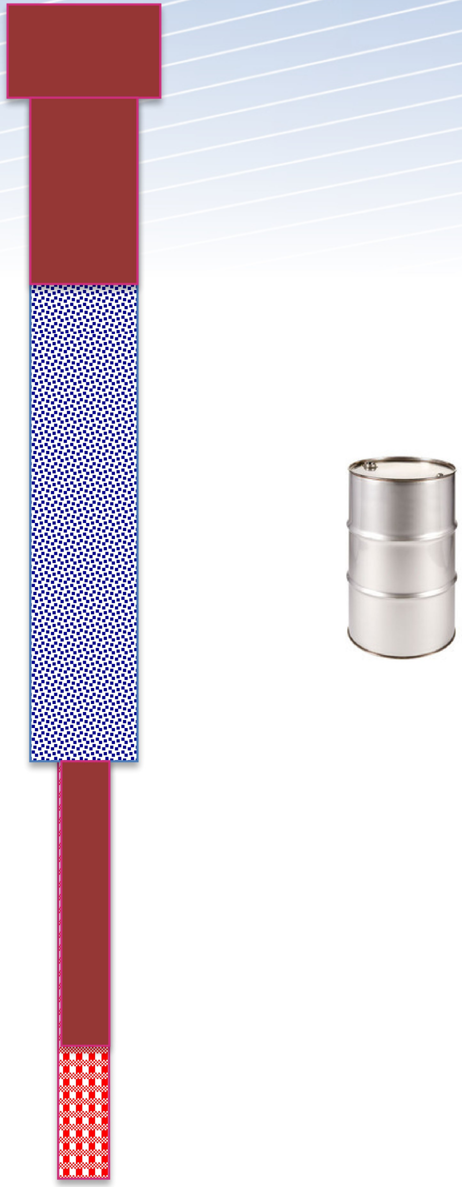
Source: Chapman, 2019

Beswick et al., 2014* propose the following design:

Depth (m)	Hole Diameter (in.)	Casing Diameter (in.)	ID mm
0-500	60	54	
500-1000	48	40	
1500-2500	36	30 (28.5 i	724
2500-5000	24 to 26	20	483

*Beswick A.J., Gibb, F.G., and Kravis, K.P. (2014) Deep borehole disposal of nuclear waste: engineering challenges. *Proceedings of the Institution of Civil Engineers*, 167, EN12. p.47-66.

A Possible Model for Research Reactor and DSRS wastes



0 to 500 m SEALS

500 to 1500 m: c. 720 mm ID

c. 400 m^3 volume

Decommissioning and operational ILW

DSRS

1500 to 1800 m SEALS

1800 to 2000 m: c. 480 mm ID

c. 36 m^3 volume

Spent fuel or reprocessing waste

Issues with RR-SF disposal

- Reactive metal matrices
- Rapid corrosion under alkaline conditions (e.g.: cement EBS); saline conditions?
- Hydrogen gas production could affect DBD seal performance
- Packaging for direct DBD disposal to mitigate these factors?
- Reprocess, as in Australia?
- ..requires more detailed assessment

Who might deploy DBD at some stage?

- **Group A:** Countries with major historic nuclear development, extensive fuel cycle facilities and complex waste inventories: the major drivers might be lack of progress with a GDF coupled with the need to show achievement in the national waste management programme, or a desire to deal with a specific waste stream (especially excess fissile materials such as separated Pu), possibly using a solution local to the source of the waste. Such countries would also be expected to have the resources and the technology to move forward with DBD.

- **Group B:** Countries with small nuclear power programmes, especially those that have opted to have their SF reprocessed, using DBD to dispose of small amounts of vHLW or SF: the driver would be the possibility of simplifying the concept for the essential national GDF and relaxing the siting and engineering requirements on it, making it easier, quicker and less expensive to design, site, operate and close.

- **Group C:** Countries with no nuclear power but with very small volumes of research reactor SF to dispose of: the driver being similar to that in Group B – segregating the disposal of SF and simplifying the requirements for geological disposal of reactor decommissioning and operational wastes.

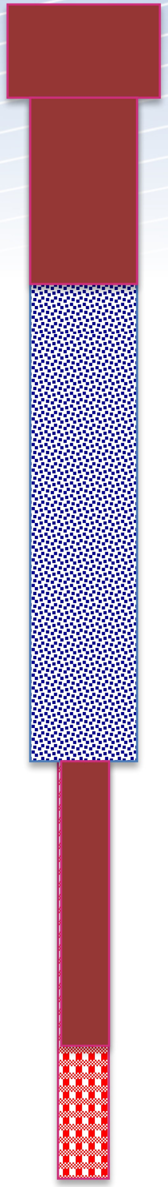
Conclusions

- DBD could be a component in the disposal strategy for national inventories with:
  - hundreds to a few thousand tonnes of LLW
  - tens of tonnes of ILW (research reactor decommissioning)
  - few tonnes of conditioned SF
  - DSRSs
- Combined surface or near-surface facility with (e.g.) a 2000 m DBD facility could be appropriate
  - depth depends on site and safety case, but greater depth will add significantly to confidence without adding significantly to costs
- DBD packaging, waste handling and sealing requires further RD&D
- DBD implementation costs in this case are likely to be of the order of some tens of MEUR
  - this is a similar range to the cost of RR decommissioning

Three possible shared development projects

1. Concept development for a borehole facility that handles all higher activity wastes at different depths, including large packages (c.f. current studies in Australia)
2. Costs study for disposal of complete small NPP-SF inventories of higher activity wastes in a DBD facility
3. Evaluation of RR-SF performance under DBD conditions and options for packaging RR-SF for DBD

A Possible Model for Research Reactor and DSRS wastes



0 to 500 m SEALS

500 to 1500 m: c. 720 mm ID

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Decommissioning and operational ILW

DSRS

1500 to 1800 m SEALS

1800 to 2000 m: c. 480 mm ID

c. 36 m^3 volume

Spent fuel or reprocessing waste

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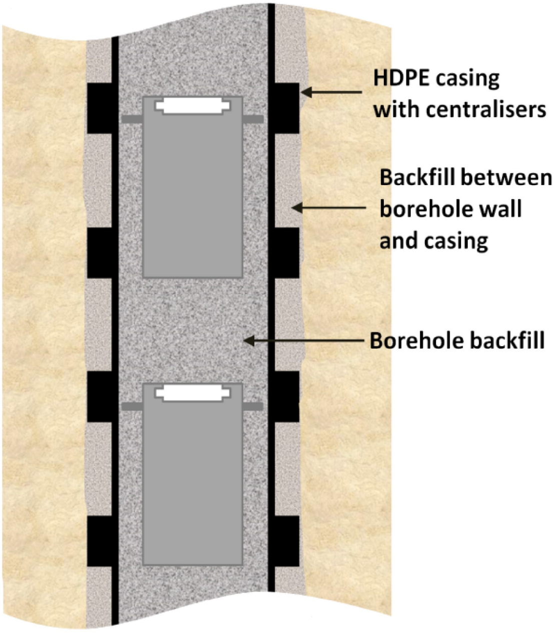
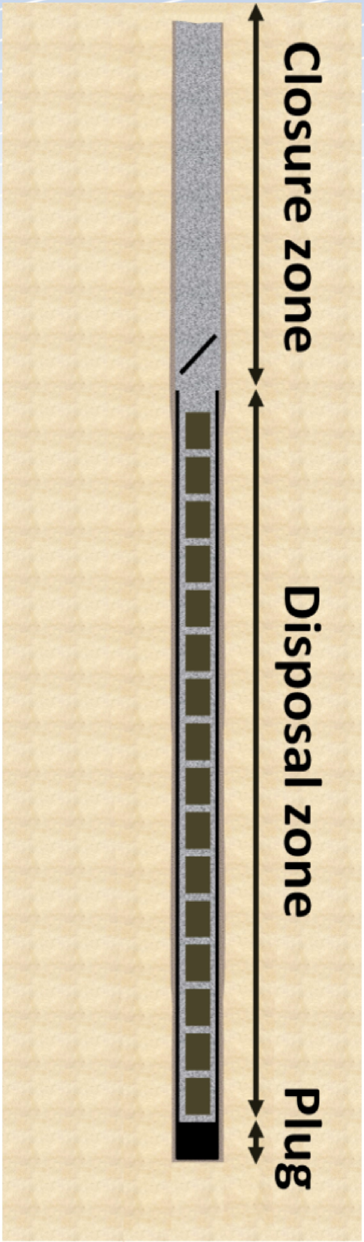
DSRS borehole disposal projects

Reference design

- waste packages are lowered into a disposal borehole (26 cm diameter) which has an HDPE casing and which is backfilled and closed
  - closure zone (minimum 30 m deep)
  - disposal zone
  - cemented bottom plug





Possible BD Project

- Using country-specific data:
  - identify design and operating concept of BD facility that would suit national inventories
    - develop country-specific scenarios for how BD might be implemented
  - assess strategic implications of incorporating BD into national disposal planning
    - what other facilities would be needed?
    - does it affect timing of storage and disposal planning?
  - assess cost implications of using BD
    - evaluate the strategic and design scenarios developed above