Planning for the back end of the nuclear fuel cycle

Our team today

Andy Griffith

- **Executive Director** of the Deep Borehole Demonstration Center
- Former Deputy Assistant Secretary for Nuclear Fuel Cycle and Supply Chain at US Department of Energy

DEEP BOREHOLE DEMONSTRATION CENTER

An independent, nonprofit, science-driven organization

- funded on a multinational, public-private partnership basis -

that aims to advance the maturity of the safety case for deep borehole disposal and the technical readiness levels of the disposal concept

Rod Baltzer

DEEP ISOLATION®

- **CEO**
- Deep Isolation is:
  - An NEI member focused on innovation across the back end of the nuclear industry
  - Founding member of Deep Borehole Demonstration Center

Nathan Snoke

HALLIBURTON

- **New Energies Global Account Manager**
- Halliburton is:
  - One of the world's largest service providers for the global oil & gas industry
  - Host of DBDC's test facility in Cameron, Texas
  - A key partner in Deep Isolation's global supply chain

What we will cover

1. The importance of focusing on spent nuclear fuel (SNF) management and disposal options right at the outset of Norway's nuclear power program
2. The strategic options Norway faces in managing spent nuclear fuel
3. More detail on the option that we three believe is right for Norway:

   deep borehole disposal

Introducing the DBDC

- **An independent, non-profit organization with a single purpose:**
  - To accelerate the global deployment of deep borehole disposal as a solution for the safe geological disposal of radioactive waste, through non-radioactive demonstration, evaluation and dissemination of learnings for borehole disposal technologies and processes, and the use of these learnings to further the generic safety case for borehole disposal.
- **Principles**:
  - Transparency, community engagement, scientific excellence
  - A long-term, phased, and prioritized approach
  - Public private partnership
  - Early results
- **Governance:**
  - A 501(c)(3) non-profit organization established in State of Texas
  - Funded on a membership basis by public- and private-sector supporters

We have been working with Norway since our inception

- **Norwegian Nuclear Decommissioning** has been a member since our launch in February 2023, as part of ERDO

ERDO working group

NND

- Since May 2023, we have been working with **Norsk Kjernekraft** through an MOU aimed at developing a demonstration repository in Norwegian crystalline rock

NORSK KJERNEKRAFT

Why this matters (1 of 3)

DEEP BOREHOLE DEMONSTRATION CENTER

1. Planning your solution for spent nuclear fuel right from the start is **vital**:

   - Early nuclear countries did not do this – and we wasted billions as a result!
   - Your disposal strategy will impact on vital 'front end' issues: e.g. siting, community engagement, financing

2. The world has not yet disposed any of the spent fuel it has created over the last seventy years ….

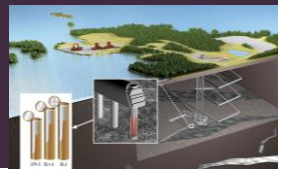
   …. and the current model for geological disposal is costly and difficult to scale:

Planned Geological Disposal Facility

UK €37.8 billion

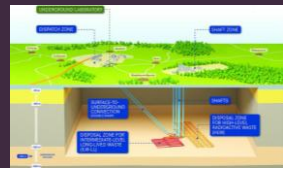
The Onkalo spent fuel repository

Finland €4.1 billion



CIGEO facility in in Meuse/Haute-Marne

France €20-35 billion



The Forsmark spent fuel repository

Sweden €8.3 billion

Source for cost estimates: Cost Comparison for Deep Borehole Disposal as Alternative to Mined Repository, Amentum 2024 (with USD converted to EUR at average 2023 exchange rate of $1 = €0.9241), except for France, where costs come from The costs of geological disposal, Professor Neil Chapman ERDO Working Group, IFNEC Workshop, Paris 11th December 2018

Why this matters (2 of 3)

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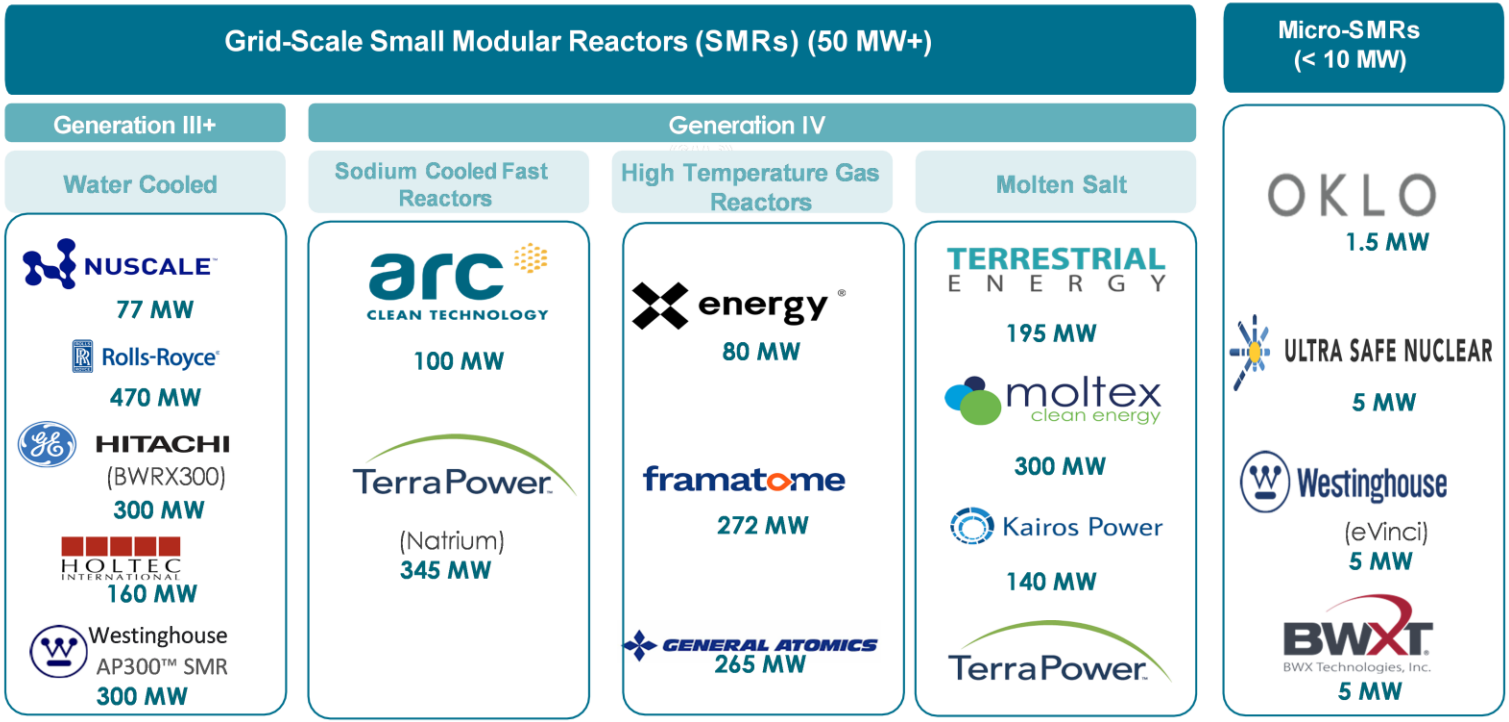
3 Spent nuclear fuel (SNF) management is about to get even more challenging ….



Source: US Nuclear Industry Council

Why this matters (3 of 3)

DEEP BOREHOLE DEMONSTRATION CENTER

3 …. and this uncertainty is a barrier to growth of the sector:

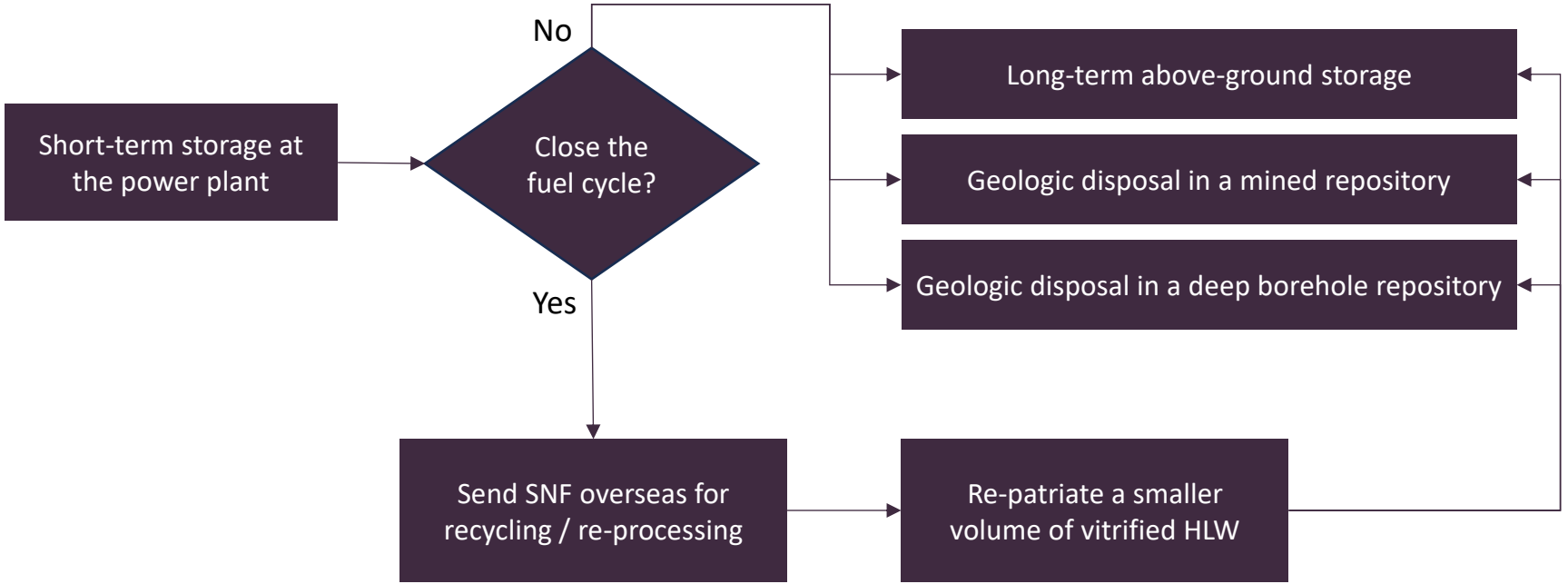
Opportunities and Barriers for Optimizing Costs across the Back End of the Advanced Nuclear Industry

DEEP ISOLATION · EPRI ELECTRIC POWER RESEARCH INSTITUTE · NEI NUCLEAR ENERGY INSTITUTE

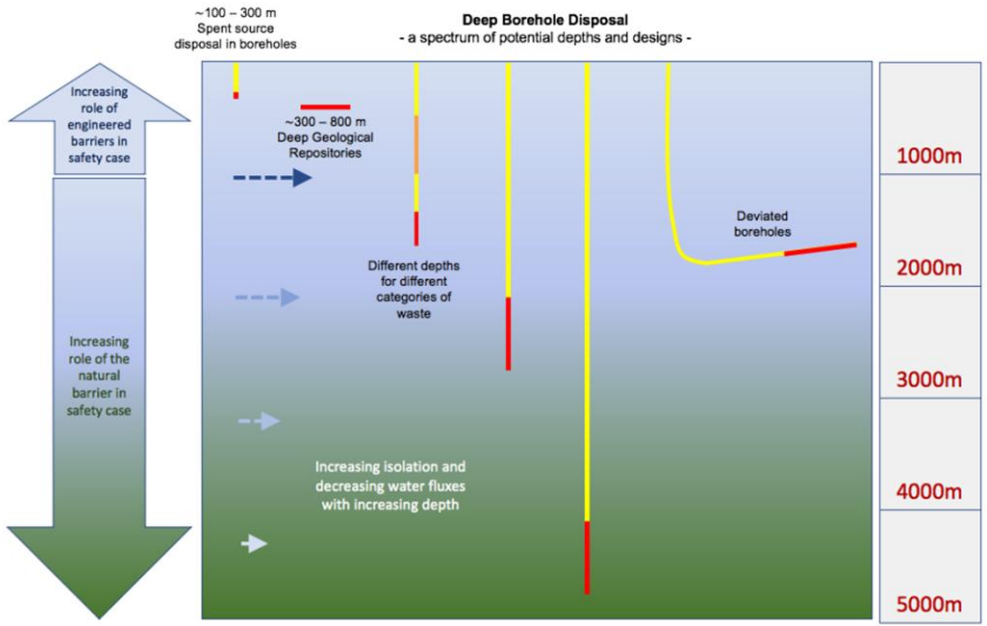
In March 2025, Deep Isolation, the Electric Power Research Institute and the Nuclear Energy Institute published results of opinion research with utilities, regulators, waste managers, policymakers, and reactor developers. Key results:

- **96%** agreed that public support for new reactors is outpacing support for waste disposal facilities.
- **92%** said that policy, funding, and attention are disproportionately focused on the reactors themselves, instead of on the back end.
- **76%** viewed uncertainty about future disposal paths as **a major source of risk and additional cost** for the advanced nuclear industry.

Spent fuel management considerations for Norway



Deep borehole disposal brings Norway new flexibility and optionality



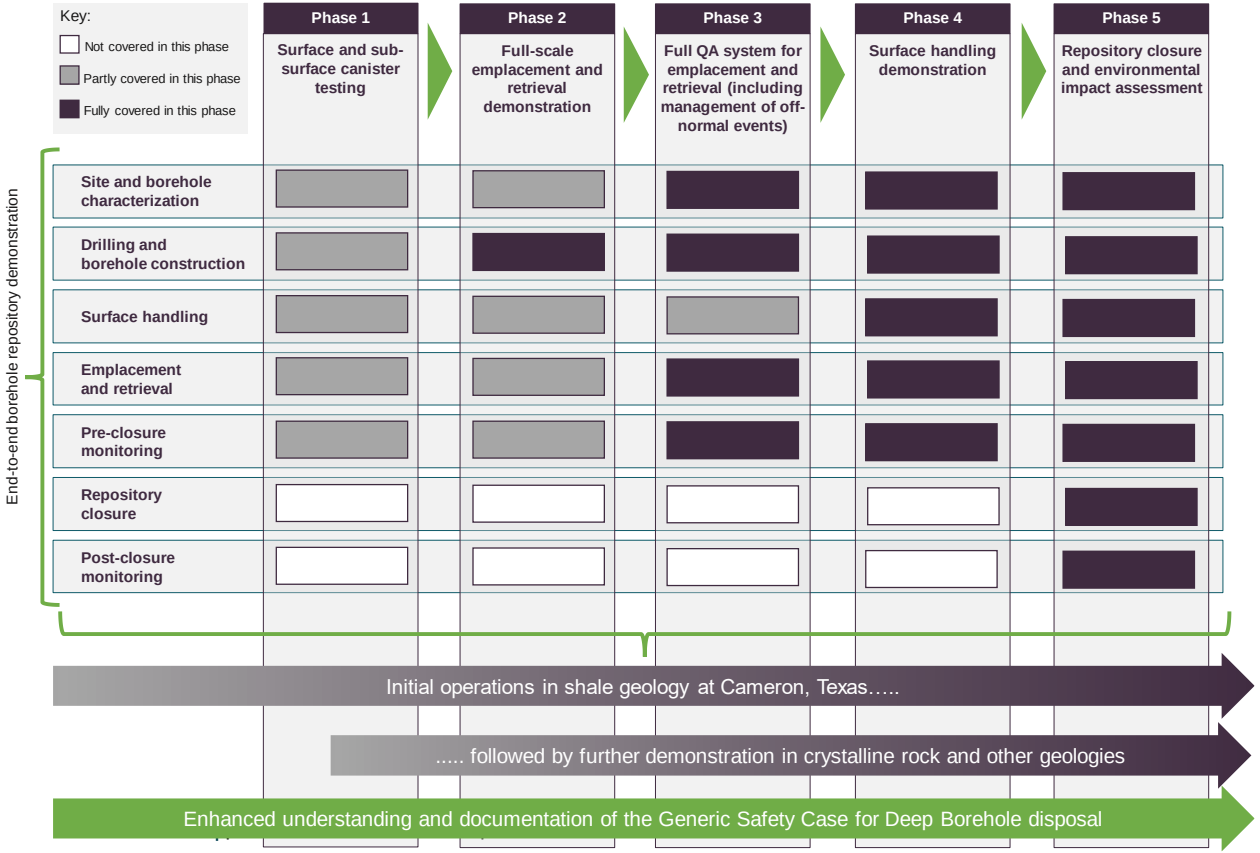
Source: IFNEC Webinar, "Understanding Deep Borehole Disposal Technology in the context of Spent Fuel and High-Level Radioactive Waste Disposal: History, Status, Opportunities and Challenges" - November 4 and 5, 2020

- Regulators, policymakers and waste management practitioners see four main benefits from deep borehole disposal:

1. Increased choice & siting flexibility
2. Potential for cost, risk and time reductions in national disposal programmes
3. Potentially attractive features from perspective of community consent
4. Potential for economies of scale around regulatory processes

- 4 out of 5 research participants would welcome greater international collaboration on deep borehole disposal – **with full-scale, end-to-end demonstration the # 1 priority**

The DBDC is delivering this full-scale demo in a phased process ….



…. and we are making strong progress

DEEP BOREHOLE DEMONSTRATION CENTER

Supported by US and international stakeholders

United States: DEEP ISOLATION, BATTELLE, slb, arpa·e, DEEP FISSION, HALLIBURTON, EPRI ELECTRIC POWER RESEARCH INSTITUTE, Southern Company

International: TNO, Department for Energy Security & Net Zero, NUCLEAR AMRC, ERDO working group, NND, NORSK KJERNEKRAFT, DANSK DEKOMMISSIONERING, COVRA NV

Organizations that have provided financial and/or in-kind support to the Center's mission

Initial full-scale PWR canister test on 23 February 2023

Class 1 UCS prototype, at Deep Isolation's fabricator (RV Industries Inc in Philadelphia), prior to shipping to DBDC for testing

Study tour to DBDC by Czech Government, Dec 2024, funded by State Dept FIRST program

Corrosion testing at pressures and fluid chemistry of disposal depths, at Halliburton facility in Carrollton, TX

Introducing Deep Isolation

About us: Deep Isolation is a US small business, established in 2016

Our technology supports storage, transportation and eventual geologic disposal of spent nuclear fuel (or vitrified high-level waste for countries that adopt a closed fuel cycle), and is supported through grant investment by the US Department of Energy and the UK Department of Energy Security and Net Zero

Focus on Europe: In 2020 we established a European business, based in London. Clients based in Europe include:

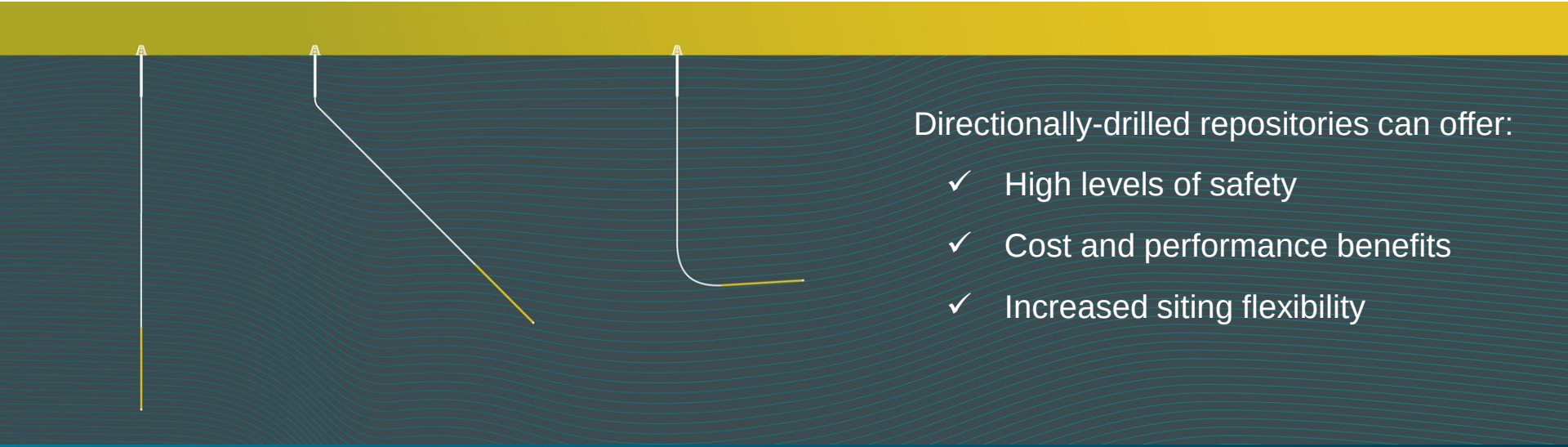
IAEA International Atomic Energy Agency
ERDO Association for Multinational Radioactive Waste Solutions
NND Norsk Nukleær Dekommisjonering
DANSK DEKOMMISSIONERING
COVRA NV
NEK DECOMMISSIONING FINANCING FUND
FERMI.
arao
NDA Nuclear Decommissioning Authority
PAO

Will quickly highlight just four features of our technology that are potentially important for Norway

Four key features of the Deep Isolation solution

1. **Repository flexibility:** we are the only organization able to offer tailored repository architectures

- We design the repository around each specific lithology and inventory
- Optimal might be vertical, deviated or horizontal – our partnerships, supply chain and our IP support all of these
- Any non-vertical borehole repository needs our patents



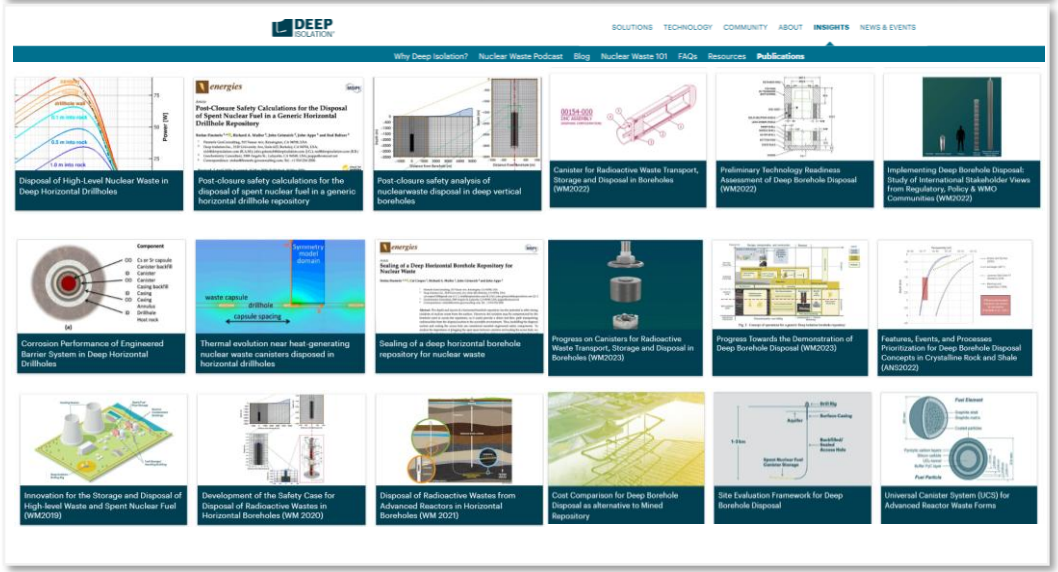
Directionally-drilled repositories can offer:

- ✓ High levels of safety
- ✓ Cost and performance benefits
- ✓ Increased siting flexibility

Four key features of the Deep Isolation solution

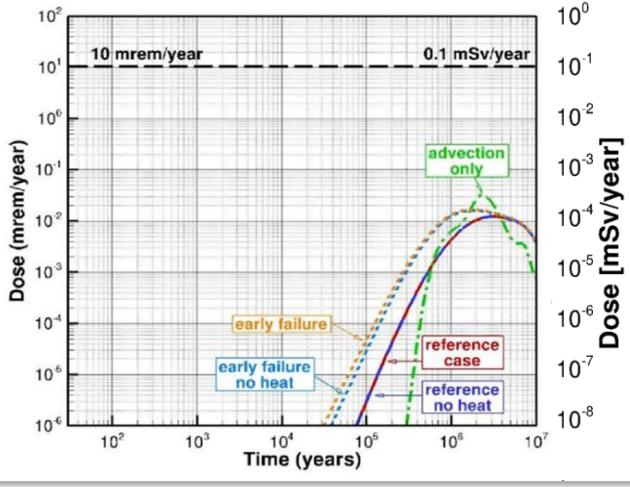
2. High levels of passive safety: our generic designs in shale and granite surpass the strictest safety requirements by a factor of 1,000, and low sensitivity to modeled accident scenarios

Deep Isolation has published extensively on safety performance of our technology



Modeled Results(1)

Key Takeaway: Peak dose is not for over 1 million years – and then will be below background radiation and 1,000x below the strictest regulatory limit



1) Post-Closure Safety Calculations for the Disposal of Spent Nuclear Fuel in a Generic Horizontal Drillhole Repository (2020) published by *Energies*.

2) Safety margin for this Generic Reference Repository is compared to a regulatory dose standard of 0.1 mSv/year. This is the strictest individual dose limit we know of that has been set for a geologic repository, by the Swiss Federal Nuclear Safety Inspectorate (ENSI, 2009). Note that when compared to requirements set by the U.S. Congress for Yucca Mountain in 40 CFR Part 191 (0.15 mSv/year) and by the IAEA in SSR 5: Specific Safety Requirements for Disposal of Radioactive Waste (1 mSv/year) the safety margin for this Generic Reference Repository is 1,500 x and 10,000 x, respectively.

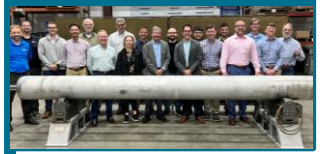
3) Even in the circumstances of a catastrophic earthquake immediately after repository closure that shears through the disposal section of the repository up to the aquifer, peak dose does not appear for 0.5 million years and 450x below the strictest regulatory limit.

Four key features of the Deep Isolation solution

3. **Maturity:** A focus on depths/diameters that leverage mature drilling technology

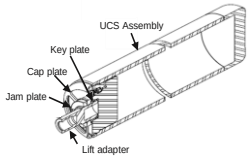
Canister #1, manufactured in UK, January 2023

Canister #2, manufactured in Pennsylvania, October 2024



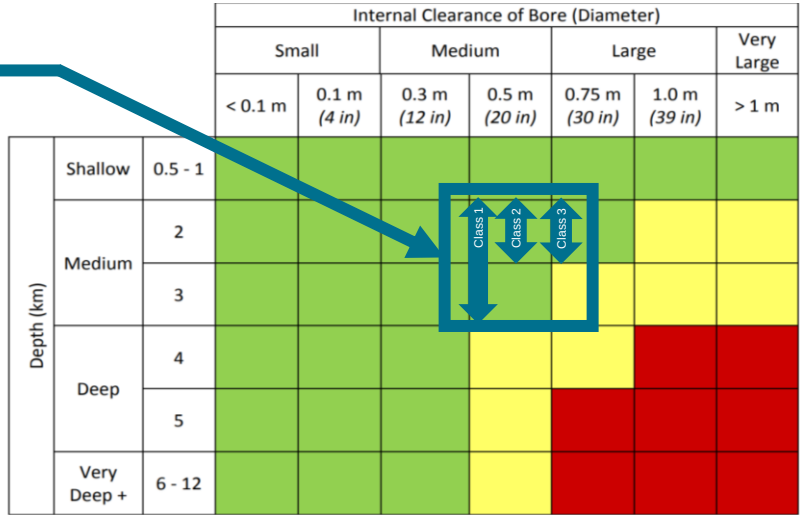
Canister #3, delivered from Nuclear Advanced Manufacturing Research Center in February 2025

Deep Isolation's Universal Canister System (UCS)



	Class 1	Class 2	Class 3
Capacity:			
TRISO blocks	0	6	6
TRISO compacts	162	198	216
Vitrified Waste Containers	0	3	3
LWR spent fuel assembly	1	0	0
Shell ID	12.75"	14.50"	17.50"
Shell OD	14.75"	16.75"	20.35"
Max weight content	2,000 lbs	2,500 lbs	4,000 lbs

Drilling for borehole disposal: EPRI/NEI/MIT maturity assessment

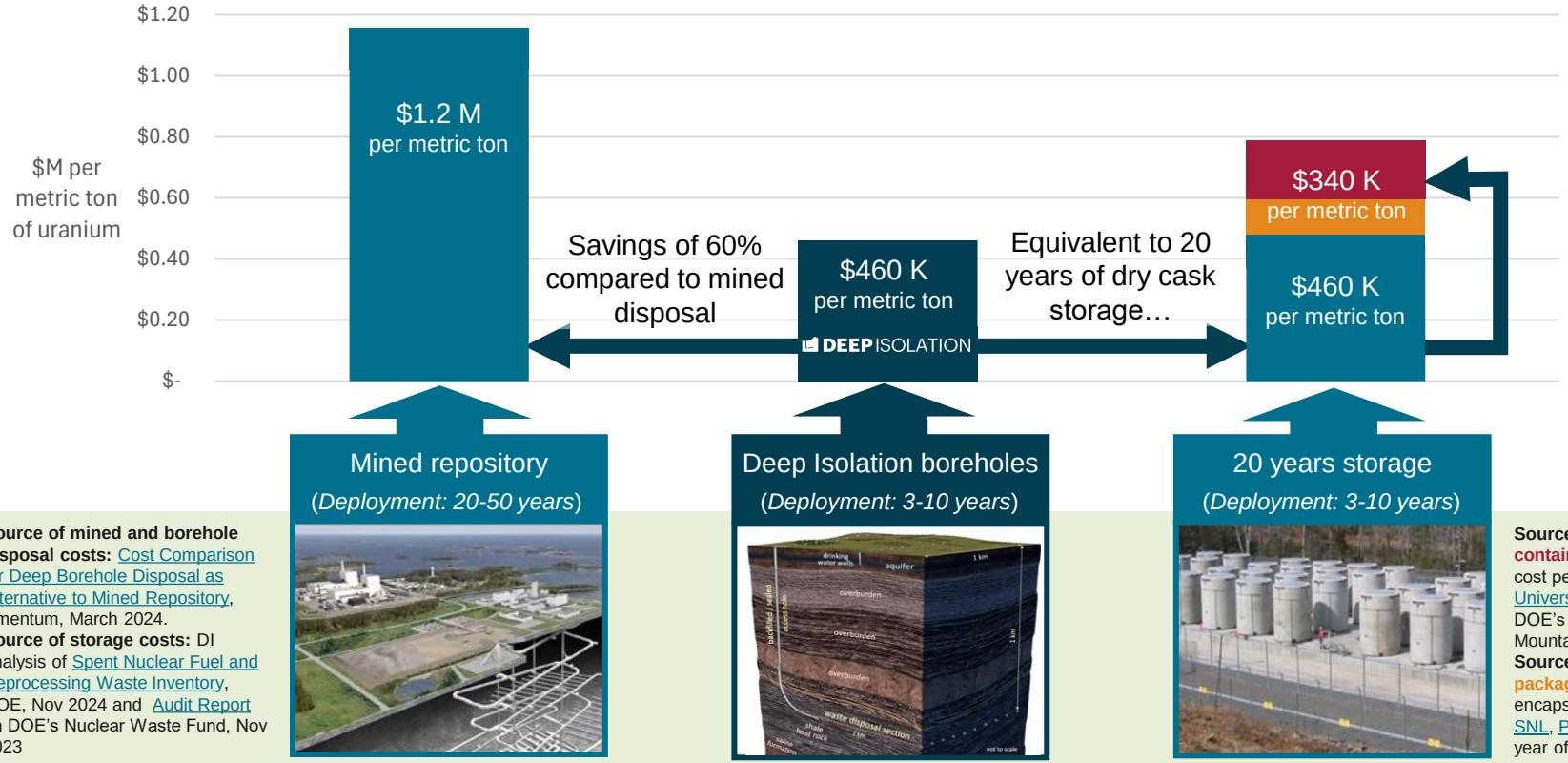


Adapted from "Why Demonstration of a Deep Borehole Disposal Concept Matters to the Nuclear Industry", A. Sowder (EPRI), R. McCullum (NEI) and V. Kindfuller (MIT), IHLRWM 2015, Charleston, SC, April 12-16, 2015

- Mature application
- Feasible application requiring modest development and involving modest uncertainty
- Beyond current technology envelope, requiring substantial development and involving large uncertainty

Four key features of the Deep Isolation solution

4. **Savings:** cost, risk and time reductions across the national waste program



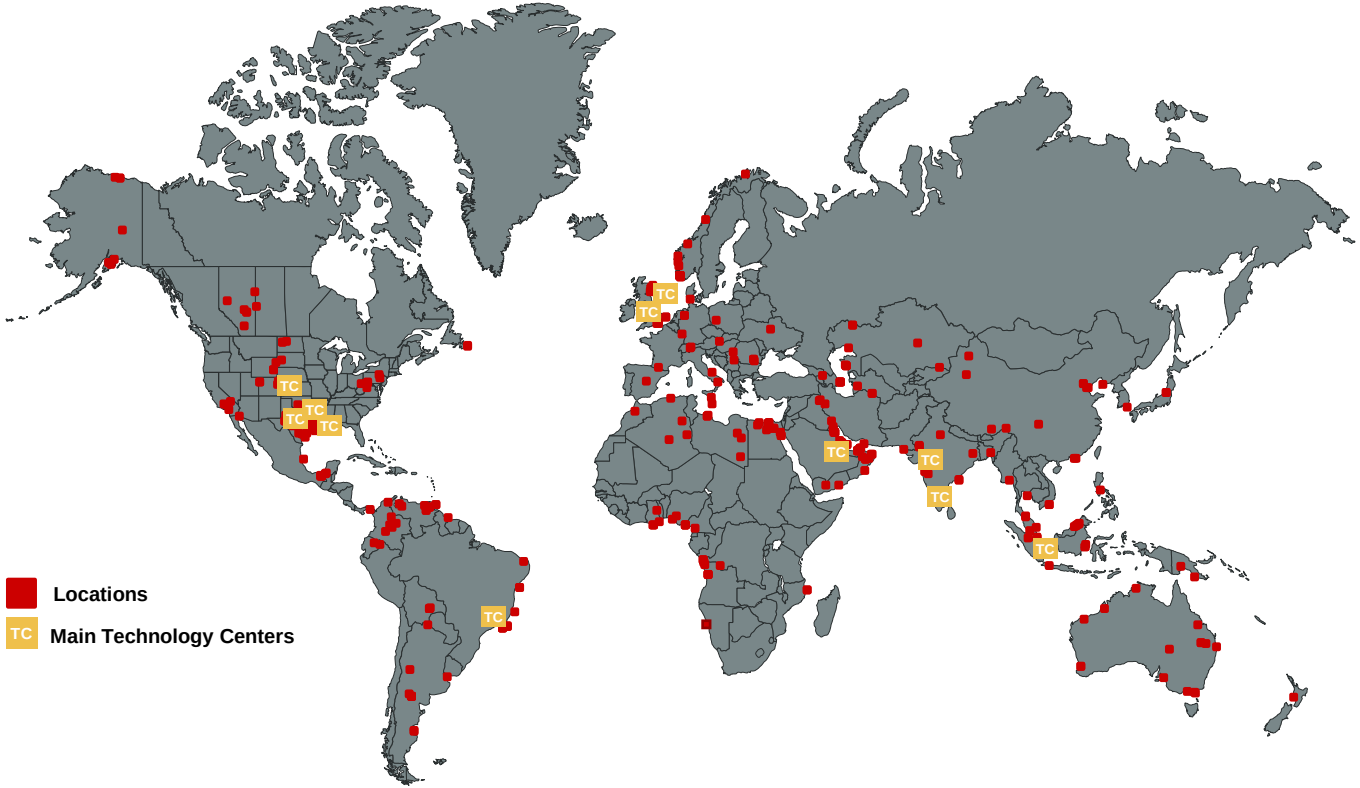
Source of mined and borehole disposal costs: Cost Comparison for Deep Borehole Disposal as Alternative to Mined Repository, Amentum, March 2024.
Source of storage costs: DI analysis of Spent Nuclear Fuel and Reprocessing Waste Inventory, DOE, Nov 2024 and Audit Report on DOE's Nuclear Waste Fund, Nov 2023

Source of costs for disposal containers: average of the 2024 cost per ton of a) Deep Isolation's Universal Canister System and b) DOE's TAD canister for Yucca Mountain
Source of costs for re-packaging: The average for encapsulation costs reported by SNL, Posiva and SKB, inflated from year of study to 2024 dollars

Halliburton Value Proposition

We collaborate and engineer solutions to maximize asset value for our customers

Halliburton global footprint



Founded

1919

Employees

40,000+

136 Nationalities

Operational Countries

70

Research Centers

11

Corporate Headquarters

Houston

HALLIBURTON

Halliburton Organization updated 2024