Deep Isolation

An introduction for Nuclear Waste Policymakers around the world

WHITE PAPER
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Deep Isolation – An introduction for policymakers

Executive Summary

The challenge: Safe, permanent disposal of nuclear waste

There is settled consensus across Governments, regulators and technical experts around the world that deep geological disposal is the preferred safe and sustainable long-term solution for nuclear waste. However, the costs of delivering a traditional mined repository are extremely high, and local communities are often resistant to hosting such a facility. Moreover, in the European Union, new regulations introduced on 1 January 2023 make clear that investment in new nuclear power can help meet EU climate and environmental objectives – but only if Member States have an operational disposal facility for high-level radioactive waste by 2050.

An alternative solution: Deep Isolation

Deep Isolation delivers the benefits of deep geological disposal in compliance with the new EU investment guidelines, but with significant additional benefits that make it a practical, lower-cost and safe option to a traditional mined repository for high-heat generating waste streams.

Deep Isolation's solution places canisters containing spent nuclear fuel or high level waste in deep borehole repositories located 1-3 kilometers underground in suitable rock isolated from the biosphere. The waste can then be retrieved for several decades or left permanently and safely (i.e. disposed of). And this can be done at or near the nuclear power plants that produce the waste, rather than in a large centralized facility.

Key benefits of Deep Isolation

Deep Isolation brings innovative technology that is altering the way governments around the world think about nuclear waste. Our solution is:

Safe: We offer the advantages of a mined geological disposal facility (GDF) and are fully in line with the political, regulatory and scientific consensus in favor of deep geological disposal. We offer borehole repositories in multiple configurations with patented new processes and technologies that ensure safety through natural geologic isolation as well as engineered barriers.

Far more affordable: The cost of disposing of nuclear waste using Deep Isolation is significantly less than a mined repository. This is in part because the diameter of our boreholes is less than 10 percent of the shafts used in mined repositories. Also, our regionally distributed model can reduce or even eliminate the costs and political sensitivities of transporting nuclear waste through communities to a central facility.

Flexible: Our solution offers great siting flexibility, because directional drilling can be used to access safe, isolated rock formations in a much greater range of locations, geologies and depths than is possible for mined geologic disposal facilities. And the modular nature of boreholes enables governments to choose between centralized and distributed models of disposal.

Simple and phased implementation: The modularity of the Deep Isolation solution allows for a staged pathway to disposal. A phased approach can be taken, beginning with as few as one borehole. And our implementation timescales are much shorter than the many years required to construct a mined repository.

Better for citizens and communities: Our research suggests communities find a Deep Isolation repository more equitable than a large mined repository. Our solution offers the potential for a win-win. We can take waste being stored above ground and put it deep underground. The significantly lower costs that result from this offer the opportunity to share savings with participating communities.

1. Introduction

1.1. About this paper

Deep Isolation offers a unique deep geological solution for nuclear waste storage or disposal.

This White Paper provides an overview of that solution and summarizes the evidence that it is:

- As safe or safer than the traditional 'large mined repository' approach to deep geological disposal
- An equitable and environmentally protective solution that has the potential to more easily secure community consent
- Dramatically less expensive.

1.2. Intended audience

This White Paper is primarily intended for policymakers in national governments who are accountable for the management and permanent disposal of nuclear waste.

It describes the problems that such policymakers are grappling with and shows how Deep Isolation can help. It also points to more detailed resources that policymakers can use when assessing the relevance of Deep Isolation to their own national circumstances.

Secondary audiences that may also find the White Paper helpful include:

- Implementing waste management organizations
- Utilities that produce nuclear waste
- Nuclear and environmental regulators
- Communities where nuclear waste is currently stored 'temporarily' above ground
- Environmental groups
- Any broader stakeholder concerned about how best to ensure the safe, permanent disposal of nuclear waste.

1.3. The problem we help solve

Since the EBR-I reactor in Idaho generated the first nuclear-powered electricity in 1951, more than 500 additional nuclear power plants have followed [1][1]. Together, these contribute more than 10 percent of the world's electrical power[2]. While nuclear power plants have no carbon emissions, they create radioactive waste that can remain hazardous to the environment and human health for tens of thousands of years.

There is clear global consensus across governments, regulators, scientists and the nuclear industry that the preferred solution for the long-term disposal of this high-level nuclear waste (HLW) is through deep geological disposal. As the International Atomic Energy Agency puts it:

> *"There is presently a broad consensus among technical experts that the preferred method of ensuring long term safety for HLW is isolation in a deep geological disposal facility. Geological disposal facilities for long-lived waste, if properly sited and constructed, provide passive,*

[1] The International Atomic Energy Agency reports in their latest survey that there are 395 operating nuclear power reactors around the world, and an additional 155 shutdown reactors in decommissioning.
[2] Source: World Nuclear Association

multibarrier isolation of radioactive materials. Emplacement in carefully engineered structures buried deep within suitable rock formations provides the long-term stability typical of a stable geological environment. At depths of several hundred metres, in a tectonically stable region, processes that could disrupt the disposal facility are so slow that the deep rock and groundwater system remain practically unchanged over hundreds of thousands or even millions of years." [1]

While many countries have yet to decide long-term policies for disposal of high-level nuclear waste, every country that has identified a complete solution has included deep geological disposal based on a traditional mined repository.

Despite that clear consensus, no country in the world has yet succeeded in fully implementing this approach.

As discussed below, two key barriers are hampering progress: high costs and the difficulty of obtaining community consent.

1.4. Mined repositories for deep geological disposal are complex and expensive

A number of leading nuclear nations have published their budgets and plans for delivering these huge engineering projects. Exhibit 1 below gives the costs for deep geological disposal that have been published by the Canadian, Swedish, UK and US government authorities.

Exhibit 1: example costs of mined repositories for deep geological disposal

Cost of a mined repository[3]	Canada [2]:	$19.8 billion
(in 2020 US dollar prices)	Sweden [3]:	$6.2 billion
	UK [4]:	$23.9 billion
	US [5]:	$122.2 billion
Cost per tonne in an average mined repository	$1.24 million	
Typical time to market	1 year from regulatory approval to start of construction	
	8.3 years for construction	

As Exhibit 1 shows, planned expenditure on deep geological disposal in these four countries alone amounts to $172 billion in 2020 prices – not including the costs of interim storage. And in view of the long lead times needed to construct a mined repository and emplace waste, significant interim storage costs need to be factored in for countries looking to build such a repository.

Extrapolating these budget figures to a global level[4], this means that the total bill for disposing of the world's nuclear waste through individual national mined repositories could cost more than $667 billion.

These very high costs have meant that most governments are not currently investing in mined repositories. Instead, they keep incurring the costs of temporary storage for nuclear waste – often in

[3] Note that the budget estimates for the four countries date from different years. Canadian, UK and Swedish figures have been converted to US dollars using average exchange rates for the relevant year from ofx.com, and all figures have been updated to 2020 values using inflation calculators published by the relevant national monetary authorities.
[4] By applying the average cost per tHM for disposal in Canada, Sweden, UK and US, as shown in Exhibit 1, to the nuclear waste identified by IAEA as currently stored temporarily by other countries.

above ground or near-surface facilities which, in many countries, are being extended significantly beyond their original planned lifespan.

1.5. Mined repositories for deep geological disposal are unpopular with local communities

Cost is by no means the only barrier to deep geological disposal in a mined repository. Most governments are committed to a policy of community consent for such an underground repository.

Deep Isolation welcomes and supports that policy; we believe no sustainable and equitable solution for nuclear waste disposal is possible if the host community does not willingly fully participate in the decision-making process and agree with the decisions that are made.

But finding a community that will consent to hosting nuclear waste from all around the country is challenging. Over the years, many governments have tried and failed to do so, due to local opposition at becoming “the nation’s nuclear waste dump.” So far, only Finland, France and Sweden have successfully completed a site selection process.

2. The Deep Isolation solution

2.1. Overview

Founded in 2016, Deep Isolation includes a team of scientists, engineers, environmentalists and entrepreneurs committed to creating the world’s safest and most cost-effective solution for the permanent disposal of nuclear waste.

In summary, our solution is:

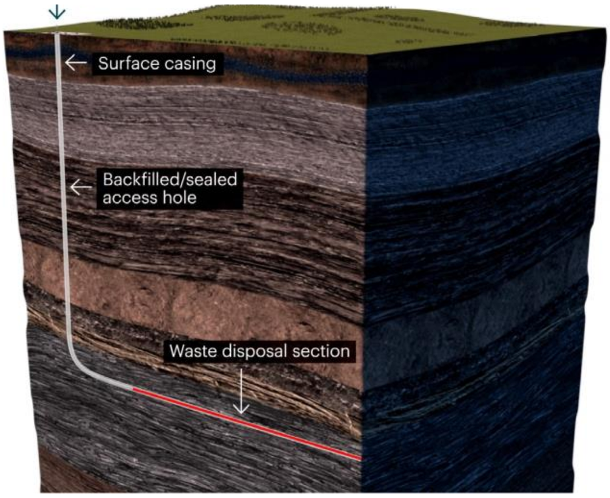
- **A form of deep geological disposal** – so it is fully aligned with the global political and scientific consensus in favor of deep geological disposal as the optimum means for disposing of nuclear waste.
- **Better for local communities** – significantly mitigating the major political and social barriers which hamper siting for a traditional large mined repository.
- **Designed with the participation of environmental groups** – Deep Isolation has long been engaging with environmental groups and is continually incorporating their input into current plans, helping earn trust and confidence.
- **Dramatically less expensive** than a mined repository that requires engineering capable of safeguarding the humans needed to work deep underground in such repositories.

The following sections describe this solution in more detail, starting with a description of how all aspects of it are deeply rooted in a set of values that have driven Deep Isolation since its creation.

2.2. Our technology

Deep Isolation's solution places waste canisters in boreholes deep underground in stable geological formations that have been out of contact with the biosphere for millions of years. We either drill vertically deep down into crystalline basement, or construct horizontal repositories in a wide range of sedimentary, igneous, and metamorphic host rocks using proven directional drilling technology.

Exhibit 2: schematic representation of a Deep Isolation repository



As illustrated, our principal reference architecture involves horizontal geometry, because this is likely to give the optimum balance of performance and cost considerations for a typical inventory in a wide range of potential geologies. Such boreholes offer an ideal isolation environment for many types of nuclear waste. The waste is emplaced in canisters, then lowered down the borehole at a typical depth of one kilometer or more and placed end-to-end into the encased horizontal section of the borehole. When ready for permanent sealing, the vertical portion of the casing is removed, then backfilled with rock, bentonite, and other materials. The radioactive waste is effectively isolated from the human environment by the depth of the repository and the thick, protective natural barrier system above it. This is the essence of deep geological waste disposal.

All our borehole designs allow for decentralized disposal of the waste at or near its current location depending on local geology. Alternatively, multiple boreholes can safely be constructed at central or regional locations. For some countries, deep borehole disposal will provide a complete solution for geological disposal; for others – with more varied inventories – they may still need a traditional mined facility for some larger waste forms, but can reduce the overall scale and cost of this by putting high-heat generating wastes at much greater depth using a "mined plus boreholes" approach.

Key features of our technical solution are summarized in Exhibit 3.

Exhibit 3: key features of Deep Isolation

Inexpensive directional drilling using proven technology
• For our horizontal borehole repositories, we place all waste in canisters buried a kilometer or more below ground in small-diameter horizontal boreholes (30 cm to 50 cm for a standard implementation), leveraging the directional drilling technology perfected over the past two decades by the oil and gas industry.
• Remarkable advances in directional drilling technology have made such deep horizontal boreholes reliable and inexpensive. In the US in the period 2007-2018, more than 120,000 horizontal wells have been drilled, with typical depths of 0.5 to 3 kilometers, and lengths of 4 kilometers or more.
• And although we use techniques from the fracking industry, we don't frack; we simply use drilling technology. We therefore do not trigger the seismic concerns that have driven public opposition to fracking.

The securest possible disposal environment
• Disposal at great depth under a billion tons of rock provides a safe, secure and permanent solution. It offers greatly reduced risks to the repository from terrorism, inadvertent human intrusion, climate change (glaciation), erosion processes, and other threats. • The reducing (low oxygen) environment at depth strongly inhibits canister and casing corrosion and dramatically slows the degradation of waste forms like vitrified HLW and UO_2 spent fuel, slowing the release of radionuclides into the geosphere. • The inherent sorptive properties of many rock formations limit the mobility of most radionuclides. And long travel paths and slow diffusion through the geosphere of mobile radionuclides (e.g. ^{129}I, ^{36}Cl, ^{79}Se) contribute to very low peak doses in the human accessible biosphere – orders of magnitude lower than the safe limits set by nuclear regulators. Most radioactive waste either decays away underground or is locked permanently in the geosphere.
Multiple engineered barriers
• Although the characteristics of the geosphere and great depth of the repositories are central to the long-term 1-million-year safety case, there are many elements of the system that contribute to the nearer term 1-100,000-year safety case. These engineered barriers perform important safety functions in the emplacement and pre-closure phase of the repository and provide additional long-term protection after the repository is sealed. • Key elements of the engineered barrier system include: **a) Corrosion-resistant canisters** Our disposal canisters provide an engineered barrier expected to last for many thousands of years. Our canisters are designed to hold complete spent nuclear fuel assemblies or other high-level radioactive waste. Canisters can be made of durable, highly corrosion-resistant stainless steel that are very stable in the hot, reducing-chloride environments found at depth. **b) Casings, Backfills, and Seals** Casing made of carbon steel provides a reliable and smooth conduit for canister placement and retrieval. The carbon steel is expected to retain its functionality for many decades or more in reducing environments. After the retrieval period, the disposal section is plugged, the casing is removed from the vertical access hole, and the vertical borehole is filled with seal types developed by US national labs and underground research labs around the world: including bentonite clays, cements, asphaltic compounds, and various rock forms used in combination. The backfilled and sealed portion of the borehole may be over a kilometer in length and provides a robust barrier to radionuclide mobility and transport. **c) Vitrified and Ceramic Waste Forms** Many common forms of HLW are themselves very substantial engineered barriers, that may contribute significantly to long term post-closure safety. Vitrified HLW may retain the bulk of its radioactive waste for many tens of thousands of years post-closure. Ceramic fuel forms such as uranium dioxide fuel pellets are even more stable in deep reducing environments and may retain the bulk of their radioactive waste for more than 100,000 years. • The combined effect of the depth of repository and geologic barrier along with a number of multiple-redundant engineered barriers deliver a high level of safety and provide confidence in the robustness of the repository system.
Minimal repackaging
• With spent nuclear fuel, the fuel assemblies that hold the waste can be placed in canisters without modification. The standard dimensions of the fuel assemblies used across the nuclear industry (20 to 30 centimeters in diameter and up to 5 meters long), are extremely well matched to borehole sizes.
Minimal transportation
• Waste transportation is minimized by the fact that there is suitable geology at or near many of the sites where nuclear waste is currently stored.

• By minimizing transport, we significantly reduce costs and the management of associated risks. • And we bring nuclear waste disposal in line with the "proximity principle" (that waste should be disposed of as closely as possible to where it is produced), which has long been a key element of international environmental law.[5]
Retrievable
• The technology to do this is highly developed, and waste can be readily retrieved for several decades in a pre-closure phase. • In the drilling industry, retrieval of objects from deep boreholes is routine, including uncooperative retrieval. Placement and retrieval of borehole equipment are highly developed and are commonly performed using wirelines with a tractor, coiled tubing, or drill-pipe methods. • Deep Isolation builds on this proven experience with additional patented retrieval technologies. The ability to retrieve waste from boreholes has been designed into Deep Isolation's solution from the start, including the overarching patented horizontal borehole repository, the design of the canister, and our emplacement and retrieval systems. • We have demonstrated the ease of retrieval of small disposal canisters using standard technologies as an initial proof of principle – as illustrated by the short video at https://www.youtube.com/watch?v=3GZ4TC8ttbE. Emplacement and retrieval of a non-fueled PWR mock-up canister was simulated above ground in February 2023 to confirm canister lift adapter compatibility with the pressure-actuated lifting equipment. Both of these tests occurred in the same location in Texas – where, with the full support of the local community, a full-scale demonstration is now being planned by the independent, nonprofit Deep Borehole Demonstration Center (see Section 4.)

2.3. Community and stakeholder engagement

Deep Isolation is committed to engagement and collaboration with local communities and governments to determine if deep geological disposal is not only right for that location but supportive of their community vision.

Our model of community partnership is built around a shared understanding of nuclear waste management. We work with all stakeholders and interested members of the public to create this partnership and build lasting relationships.

Typically, a government agency will take the lead in management of the siting process and community engagement. We support that with people, skills and processes to facilitate a fully immersive and two-way dialogue with local communities and decision-makers.

We are committed to:

- A successful outcome, in which informed consent is achieved through listening, transparency and accessibility.
- Engaging in detailed, public discussions on the design and scope of our proposed solution.
- Providing thoughtful responses to the ideas, concerns and information received from interested parties.

[5] See for example the 1989 Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, and the European Union environmental and municipal waste management policy, introduced in Article 5 of the Waste Framework Directive (75/442/ EEC)

Throughout this process, our aim is to work with our government clients and partner communities to ensure that all three criteria described in Exhibit 4 are achieved in full.

Exhibit 4: criteria for a Deep Isolation partner community

Community value

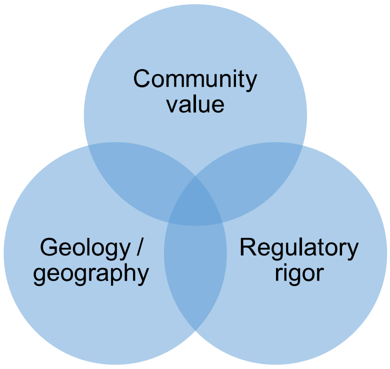
- ✓ The decision to host a Deep Isolation facility is voluntary and resides with the host community.
- ✓ The community believes it will be better off for hosting a Deep Isolation facility.
- ✓ The benefits or compensation associated with hosting a Deep Isolation facility will be successfully negotiated with the host community.

Geology / geography

- ✓ The site is located within a suitable geologic environment.
- ✓ The site is not subject to cultural restrictions or significant subsurface resource extraction.
- ✓ Pore water at depth can be shown through isotopic analysis to have been isolated from the environment over geological periods of time.

Regulatory rigor

- ✓ Sufficient regulatory oversight and review of the facility is maintained throughout the life of the facility.
- ✓ Local support, in conjunction with technical submittals needed to secure necessary approvals, is maintained throughout the life of the facility.



2.4. Planning expertise and delivery partnerships

Deep Isolation works closely with clients to develop an implementation roadmap that is rooted in the local context, with the skills recommended by the IAEA for development of a feasibility study in the nuclear sector [6]:

- Technical expertise to evaluate different options from an engineering and geological perspective
- Project and management system expertise
- Detailed knowledge of the country, relevant communities, and the regulatory environment
- Legal and business expertise
- Financing expertise
- Expertise in stakeholder communication and public information.

National waste management organizations need flexibility and choice to evaluate, plan and implement deep borehole disposal projects safely and effectively. Deep Isolation aims to be the partner of choice with responsive, trusted engagement and flexible offerings:

- **Planning services:** We work with your team to evaluate deep borehole disposal against other options, plan your implementation pathway and develop the repository design and safety case.
- **Building-block projects:** We offer one or more individual services rather than an integrated whole if this is what clients want.

- **Licensed IP and support:** We provide licensed access to our operational IP and technology IP, including training, support and ongoing development, for use either directly by you as our government client or by your contracted suppliers.
- **Full-service delivery:** Deep Isolation and our partners design, deliver and operate the end-to-end solution as an integrated and quality-assured program of work.

Exhibit 5: Deep Isolation technical advisers

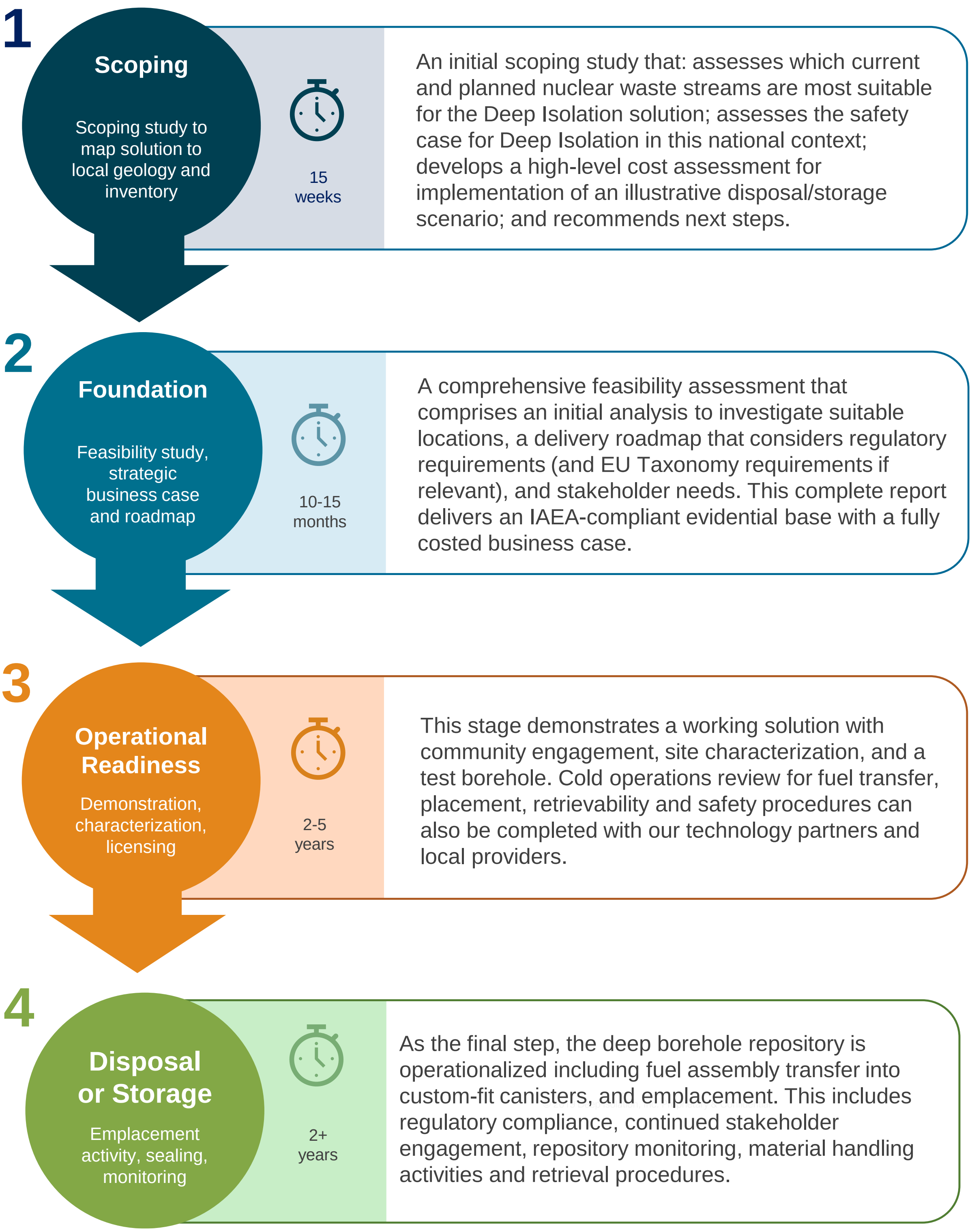
amentum	Global technical and engineering services leader supporting critical programs of national significance across defense, security, intelligence, energy, and environment. • Licensed reseller • Technical and engineering services
NAC INTERNATIONAL	A leading nuclear fuel cycle consulting and technology solutions company with over fifty years of experience in the nuclear industry, NAC International has delivered more than 500 storage and transport systems. They bring decades of experience in designing, engineering, licensing, operating and maintaining systems for storage and transport of nuclear materials. NAC International partners with Deep Isolation for: • Design, development, and manufacturing of disposal canisters, transfer casks, and transportation casks • Equipment and services for used nuclear fuel and high-level waste handling • Licensing support.
slb	The world's leading oilfield services provider, SLB: • brings us leading-edge drilling technology • has already assisted in demonstrating our solution in a live environment, emplacing and retrieving canisters from a SLB borehole.

2.5. Phased implementation

We have designed a phased and gated implementation process, using iterative systems engineering combined with intensive stakeholder engagement. This provides nuclear power programs with an evidence-based path for implementing their corresponding waste management program to decide — with community consent — to permanently dispose of nuclear waste using Deep Isolation's solution.

This Deep Isolation Roadmap process consists, at a high-level, of four phases as illustrated below. A more detailed description of our Deep Isolation Roadmap process – including how it aligns with and implements IAEA's guidance [7] on the design of radioactive waste repositories – is set out in a further white paper: *Deep Isolation Roadmap: an introduction*, which is available through enquiry at emea@deepisolation.com.

Exhibit 6: the Deep Isolation Roadmap: four phases to assess, plan, test and implement



Within the European Union (EU), the Taxonomy Regulation requires that, for new nuclear energy activities to be recognized as contributing to climate change mitigation, Member States should amongst other things have in place a detailed plan to have in operation, by 2050, a disposal facility for high-level radioactive waste (including spent nuclear fuel).

It is generally recognized that only a few countries such as Finland, Sweden and France can meet this date with their current plans for developing a mined repository for nuclear waste. However, there are a number of other Member States which are interested in pursuing new nuclear projects, but whose plans for a mined facility extend beyond the 2050 date. The Deep Isolation solution will enable these Member States to meet the 2050 criterion, using the above four-phase process.

Case studies of our work with government organizations to take forward this phased roadmap are published at [Resources – Deep Isolation](#).

2.6. The safety case for Deep Isolation

Safety is at the heart of what we do at Deep Isolation. We are committed to:

- **Delivering safety in practice**, and over geological timeframes. (Our published models calculate radiological safety over a period of 10 million years.)
- **Investing in the data, evidence, modelling and scientific analysis** that is needed to demonstrate, quantify and document the safety of Deep Isolation.
- **Engaging with the scientific community** in order to continually challenge and improve that evidence and analysis – both through formal peer review processes and by open publication to facilitate ongoing critical scrutiny by all stakeholders.

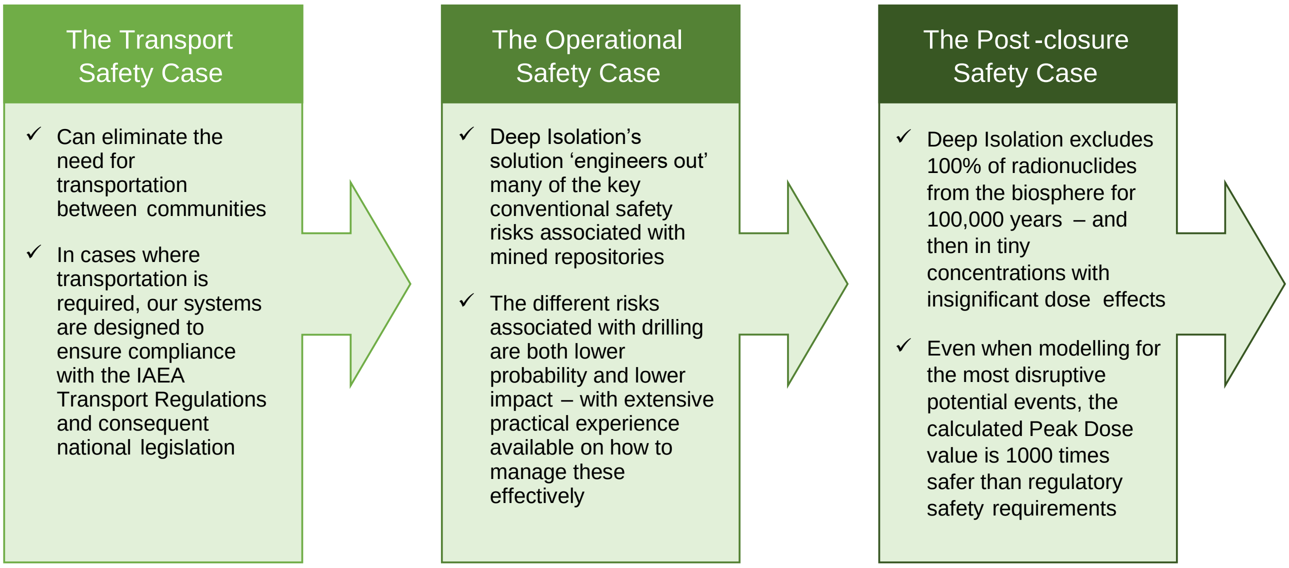
Our work so far suggests two core conclusions:

1. **In terms of radiological safety**, Deep Isolation delivers:
   - ✓ All of the safety benefits of a traditional mined geological repository
   - ✓ Safety levels for post-closure performance that are orders of magnitude higher than those required by any nuclear regulator in the world.
2. **In terms of conventional safety**, Deep Isolation delivers significant <u>additional</u> benefits:
   - ✓ Potential to eliminate or significantly reduce the need for transportation between sites
   - ✓ Elimination of a range of key risks associated with building and operating mined repositories that require human presence underground.

As summarized at Exhibit 7 below, these emerging conclusions flow from:

- A qualitative assessment of safety considerations across all three phases of the lifecycle for a Deep Isolation repository: transportation (if necessary) of waste to the disposal site; construction and operation of the repository; and the long-term environmental safety of the repository once it has been sealed off.
- Detailed quantitative modelling of the post-closure safety case.

Exhibit 7: overview of the Safety Case for Deep Isolation



Deep Isolation's published modelling and safety calculations [8] [9] support a robust safety case with inherent passive safety in a wide range of geologic settings. Furthermore, the calculations suggest that the overall safety goal of isolating the waste from the accessible environment is inherently supported by the properties of the geosphere, the depth of the repository, and the attributes of its configuration. Long-term confinement of radionuclides in the stable waste matrix and long migration times allow for radioactive decay to occur within the repository system, considerably reducing the activity of radionuclides potentially being released to the accessible environment.

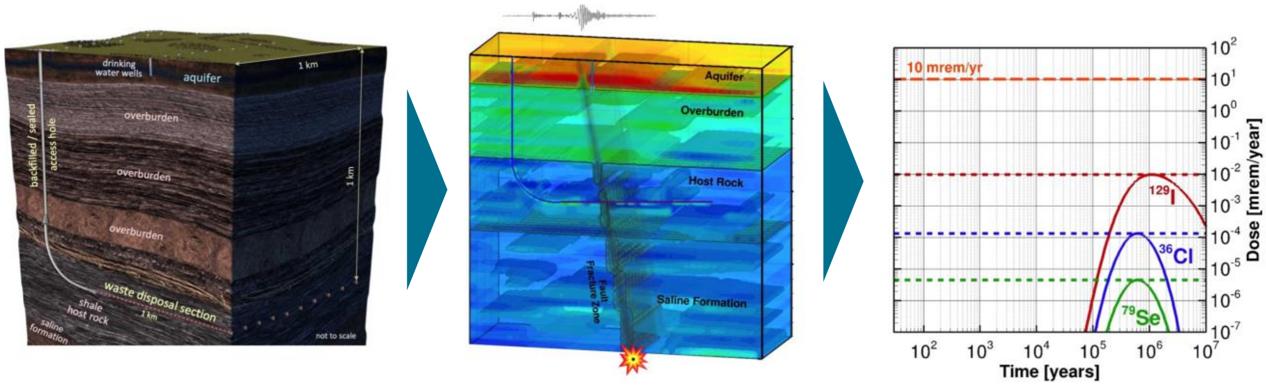
Exhibit 8 summarizes key findings from our reference case for disposal of spent fuel assemblies in a horizontal borehole repository in generic shale host rock.

Exhibit 8: calculating radiological safety of Deep Isolation

A deep horizontal borehole system located in shale ….

….used as the basis for a computer model …..

….. that estimates radiological exposure dose over 10 million years



This analysis shows that:

- The estimated maximum annual dose is low: approximately 0.01 mrem (0.1 microsieverts) per year – which is 1,000 times smaller than a regulatory dose standard of 10 mrem (100 microsieverts) per year.
- This dose estimate is robust to changes in key assumptions and uncertainties in the model parameters. For example, the analysis models the impact of early canister failure – and even instant release of the entire radiological budget of the repository into the geosphere at day one. This shows that peak doses remain both very late arriving (1-3 million years) and very low.

Furthermore, the calculations suggest that the overall safety goal of isolating the waste from the accessible environment is inherently supported by the depth of the repository and the attributes of its configuration. Long-term confinement of radionuclides in the stable waste matrix and long migration times allow for radioactive decay to occur within the repository system, considerably reducing the activity of radionuclides potentially being released to the accessible environment.

The above calculations relate to shale geology. Deep Isolation has also completed a computer simulation calculation for a generic granite repository [9] which demonstrates that, despite the assumed long-range connectivity of the fracture network, the safety of higher-strength rock is comparable to that in sedimentary rock.

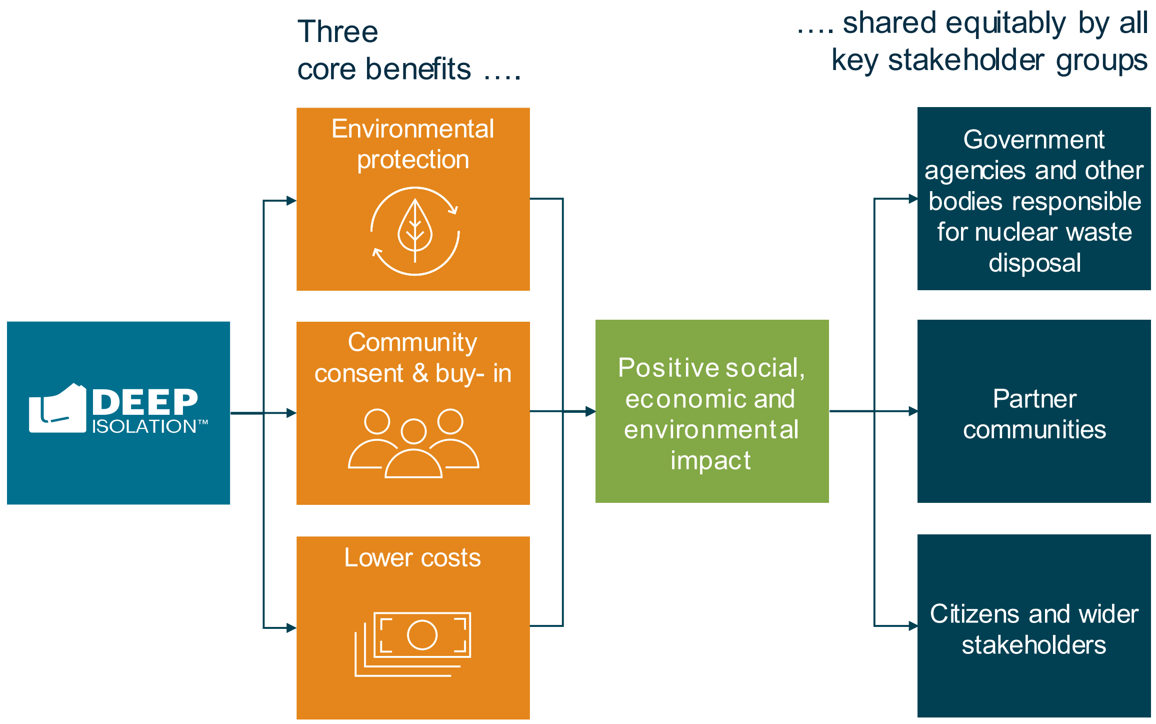
The calculations and safety considerations summarized here are, necessarily, generic. That is, they do not derive from a specific geographic location or geological site. Deep Isolation will work with any community considering implementation of a Deep Isolation repository to develop a comprehensive site-specific Safety Case. This work is an integral part of the Deep Isolation Foundation Study described at Section 2.5 above.

3. The outcomes we help deliver

3.1. Overview

The Deep Isolation solution brings significant benefits. Crucially, it creates social, economic and environmental value that is shared equitably across all key stakeholder groups, as illustrated by Exhibit 9.

Exhibit 9: how Deep Isolation delivers social, economic and environmental impact



Section 3.2 describes these benefits in more detail. Section 3.3 then provides additional evidence to quantify one core benefit in particular: the lower cost of Deep Isolation when compared with other technologies for deep geological disposal.

3.2. Delivering benefits for all stakeholders

Deep Isolation aims to create benefits shared equitably by all stakeholders, in order to ensure our solution commands widespread and sustainable support. A summary of key benefits, as experienced from different stakeholder perspectives, is shown in Exhibit 10 below.

Exhibit 10: multi-stakeholder benefits from Deep Isolation

	Benefits for government	Benefits for partner communities	Benefits for citizens
Environmental protection	✓ **A safe and secure solution** for permanent nuclear waste disposal ✓ **Compliant with IAEA** recommended best practices [10], using deep geological disposal to provide the safest solution ✓ **Respects the 'proximity principle'** for waste management that is embedded in international law ✓ Meets the EU Taxonomy requirements for green nuclear investment.	✓ **A new option for local communities with nuclear facilities.** Deep Isolation takes waste currently above ground in temporary storage facilities – and provides a safer, permanent and secure disposal deep underground.	✓ **Minimizes the need for transportation** of nuclear waste between communities ✓ **At least four out of five citizens surveyed agree**[6] that nuclear waste should be put into permanent disposal below ground and transportation should be minimized.
Community consent and buy-in	✓ **A politically viable way forward** on nuclear waste disposal that can earn the support of stakeholders ✓ **Enables a less centralized model of waste disposal.** Because boreholes can be deployed modularly in multiple locations, they enable a shared model across multiple communities – so no need for any single community to sign up as the nation's sole 'nuclear waste dump'.	✓ **A more equitable approach.** Deep Isolation empowers communities to safely dispose of waste from nuclear energy generated in their community – without needing to consent to hosting a central nation-wide facility.	✓ **At least four out of five citizens surveyed agree**[7] that Deep Isolation should be considered by policymakers as an option to deliver deep geological disposal.
Cost savings	✓ **Dramatically lower costs** – because we use drilling technology rather than creating large mines that require human intervention underground ✓ **Affordable for smaller countries** with a smaller waste inventory that may never be able to afford the costs of a large-scale mined repository ✓ **Mature technology** – once approval to proceed has been given at a specific site, we can drill and start disposing of waste safely and securely within 1-2 years – compared with the decades-long timeframes associated with building massive centralized repositories. ✓ **Reduces need for expensive "temporary storage".**	✓ **Cost savings can be re-invested in partner communities.** The significantly lower costs flowing from Deep Isolation offer the opportunity to share savings with participating communities.	✓ **Frees up huge amounts of government expenditure**, enabling potential tax decreases or increases in other government program areas – and eliminating the need for additional disposal fees on electric bills.

[6] Based on a survey across 23 states in the US, conducted by polling firm GfK in 2019
[7] Based on a survey across 23 states in the US, conducted by polling firm GfK in 2019

3.3. Cost savings from Deep Isolation

As Exhibit 10 above explains in summary, a Deep Isolation repository offers significant cost savings when compared to a mined repository.

Detailed costs will vary according to the specific context of each implementation – including the specific geology, volumes and types of waste to be disposed, proximity of disposal sites to current location of waste, national regulatory requirements and local community needs. Developing the business case for Deep Isolation disposal is therefore a core part of our phased offer as described in Section 2.5 above:

- Initially, we develop high-level costings to inform initial policy-making, as part of the Deep Isolation Scoping Study.
- Then, we develop more detailed and site-specific costs to inform investment decisions, as part of the Deep Isolation Foundation Study.

Whatever the local context, the key drivers of Deep Isolation's greater cost-effectiveness include:

- **Lower construction costs:** our boreholes are less than 10 percent the diameter of the shafts used in mined repositories and can be delivered using proven and widespread drilling techniques.
- **Lower operational costs:** our patented emplacement and monitoring technologies remove the need for human activity underground, removing a significant driver of both cost and safety risk.
- **Lower transport costs:** our regionally distributed model can reduce and even eliminate the costs and political sensitivities of transporting nuclear waste through communities to a central facility.
- **Faster implementation:** the governments that are currently engaged in developing mined repositories measure the timescales for planning and constructing these in decades; Deep Isolation can start disposing of waste in 1-2 years following regulatory approval.
- **Avoided costs of storage:** these significant time savings mean that governments and industry can avoid the very significant costs that they would otherwise incur from temporary storage of nuclear waste. (In the US alone, the federal government is currently forecasting that it will spend more than $28 billion between 2019 and the earliest time its planned disposal facility at Yucca Mountain might be made available [11].)

At Exhibit 11 below, we summarize the results of an extensive study that we have undertaken to quantify these cost savings in the context of the United States. This compares the US Government's own published costs for a proposed mined repository (at the candidate site of Yucca Mountain in Nevada) with 2020 costs of disposal for a horizontal borehole repository through Deep Isolation, based on Deep Isolation's internal and service provider partner estimates.

The key finding is that deployment of Deep Isolation's solution to dispose of all of the current and planned nuclear waste in the US would save taxpayers $90 billion – cutting the lifecycle cost of disposal at Yucca Mountain by more than half.

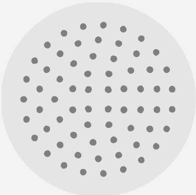
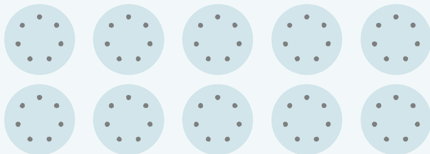
Exhibit 11: comparing two models of deep geological disposal for the US

Current planned model	Deep Isolation's horizontal borehole

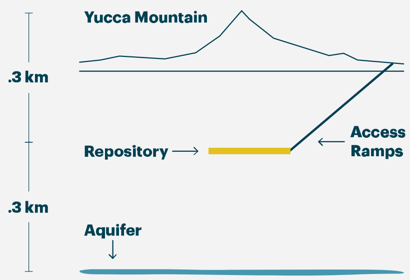
Scope of nuclear waste for disposal

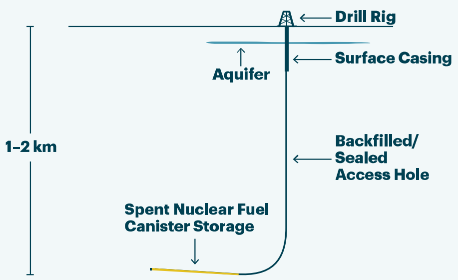
151,800 metric tonnes of nuclear waste
(current stockpile, plus estimated future commercial spent fuel)

Transport model:

Current planned model	Deep Isolation's horizontal borehole
 **Centralized** Transport all nuclear waste from 76 sites across the US to a single repository at Yucca Mountain, Nevada	 **Distributed** Use regional hubs for disposal of commercial spent fuel and government waste

Engineering solution:





Time to market

Current planned model	Deep Isolation's horizontal borehole
35 years Assume Yucca Mountain project restarts, with licensing and construction complete in time to receive waste by 2055	**5 years** Assume the regional hubs are available from 2025 – initially under an interim storage licence

Cost model

Current planned model	Deep Isolation's horizontal borehole
• Total cost for disposal of current and planned nuclear waste: $171 billion	• Total cost: $82 billion • Saving = $89 billion = 52% saving

Deep Isolation therefore offers highly significant cost savings even in a country with as complex and geographically distributed nuclear waste inventory as the US. A country with an inventory that is smaller and simpler (for example, focused only on spent fuel), will see even more significant savings.

In Exhibit 12 below, we look at illustrative costs for using Deep Isolation in a scenario to dispose of waste from two reactors on a single site, at a horizontal borehole repository at or near that site. This represents a saving of $2 billion, or 70 percent, compared with the cost of disposing in a typical mined repository as discussed in the analysis of Canadian, Swedish, UK and US repository budgets at Section 1.1 above.

87 percent of this $2 billion saving flows from the significantly lower cost of building a Deep Isolation repository. The remaining 13 percent flows from our speed of implementation[8], which reduces the need for parallel expenditure on temporary storage.

Exhibit 12: costed scenario for a Deep Isolation repository

Scenario

Inventory for disposal: 4,200 spent nuclear fuel assemblies, representing 2,000 tHM

Siting: inventory is from two decommissioned reactors at a single location

Geology: sedimentary rock such as shale

Our delivery

Ready to start disposal within 1-2 years of regulatory approval

Phased construction of 20 horizontal boreholes on the site, each with diameter of 44 cm

Time taken for full disposal: $5\frac{1}{2}$ years, at an average disposal rate of 15 canisters per week

Our costs

Disposal: $724 million

Storage: $132 million for interim storage of waste during time from regulatory approval to full disposal

Total cost: $856 million

Cost per tHM: $427,814

Benefits

Total saving = $2 billion

Percent saving = 70%

Compared with typical cost of a mined repository. Both Deep Isolation and mined repository costs include interim storage between regulatory approval and final disposal.

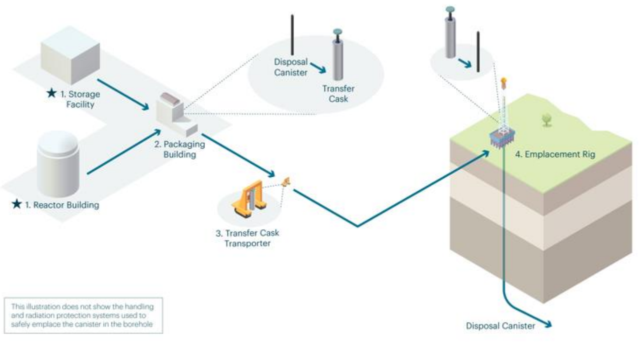
[8] The Deep Isolation implementation times shown in Exhibit 12 are compared with our analysis of mined repositories at Exhibit 1. This shows a typical mobilization period of 1 year and a typical construction period of 8.3 years for a mined repository. For emplacement times, we have used the fastest published rate (which is the US Government's plan to emplace 3,000 tHM pa once its repository is operational).

3.4 The potential benefits of Deep Isolation as a temporary storage solution

The benefits described above focus on the use of Deep Isolation for permanent disposal of nuclear waste. But increasingly we find policymakers are asking us about the role Deep Isolation might play as a temporary storage solution.

Our initial view is that, from the perspectives of both technical feasibility and commercial viability, Deep Isolation would be competitive over the medium term with existing temporary storage solutions such as dry cask storage or spent fuel pools. The Deep Isolation solution is fully retrievable, and the low cost opens up the option of a community using our solution to store its waste temporarily, pending disposal in the future. The key potential benefits of Deep Isolation in this context are summarized at Exhibit 13.

Exhibit 13: Deep Isolation as a potential solution for temporary storage



Economic benefits

- The economic argument for using Deep Isolation's solution as an alternative to above-ground temporary storage likely becomes compelling after 10 to 20 years, depending on factors such as type of waste, location and geology.
- After this time, the Deep Isolation storage solution is significantly more economical, with potentially a 50 percent or greater savings over 20 - 40 years.

Environmental and security benefits

- Temporary storage of nuclear waste deep below ground and isolated from the biosphere is safe and environmentally-friendly.
- It is also more secure from both deliberate and inadvertent human intrusion, being effectively inaccessible without specialist heavy drilling equipment.

Flexibility and choice

- Deep Isolation gives communities flexibility to shift from storage to disposal. This change is fundamentally one about regulatory approval and community consent rather than technical implementation.
- That is because the Deep Isolation solution for temporary storage is essentially the same as for disposal; the chief difference is that boreholes are not sealed permanently.
- This means there is the option to convert from temporary storage at any point after the usual monitoring period. At this point, the majority of disposal costs will already have been paid for during interim storage.
- The retrievability feature built into Deep Isolation's solution, means that waste could be removed and inspected, prior to a decision to convert from interim storage to permanent disposal.

However, there are clear regulatory and community consent issues to consider in this regard. We very much welcome views from stakeholders on the attractiveness of Deep Isolation in the context of temporary storage.

Meanwhile, we are working – with financial support from the US Department of Energy's ARPA-E program – to develop the intellectual property in our PWR disposal canister into a Universal Canister System (UCS) [12]. The UCS will deal with PWR fuel and also a wide range of advanced nuclear fuels coming to market. Crucially, it will function safely as an above-ground storage package for spent fuel and high-level waste, integrating flexibly and efficiently with existing storage technologies. This will enable waste owners to optimize the lifetime costs of waste management, by removing the need for costly repackaging ahead of eventual disposal.

4. The Deep Borehole Demonstration Center

It is clear that policymakers around the world see great potential value in deep borehole disposal, but need to see a full-scale demonstration.

A twelve-month research program across eighteen countries by Deep Isolation and the University of Sheffield, published at Waste Management Symposium 2022 [13], shows that:

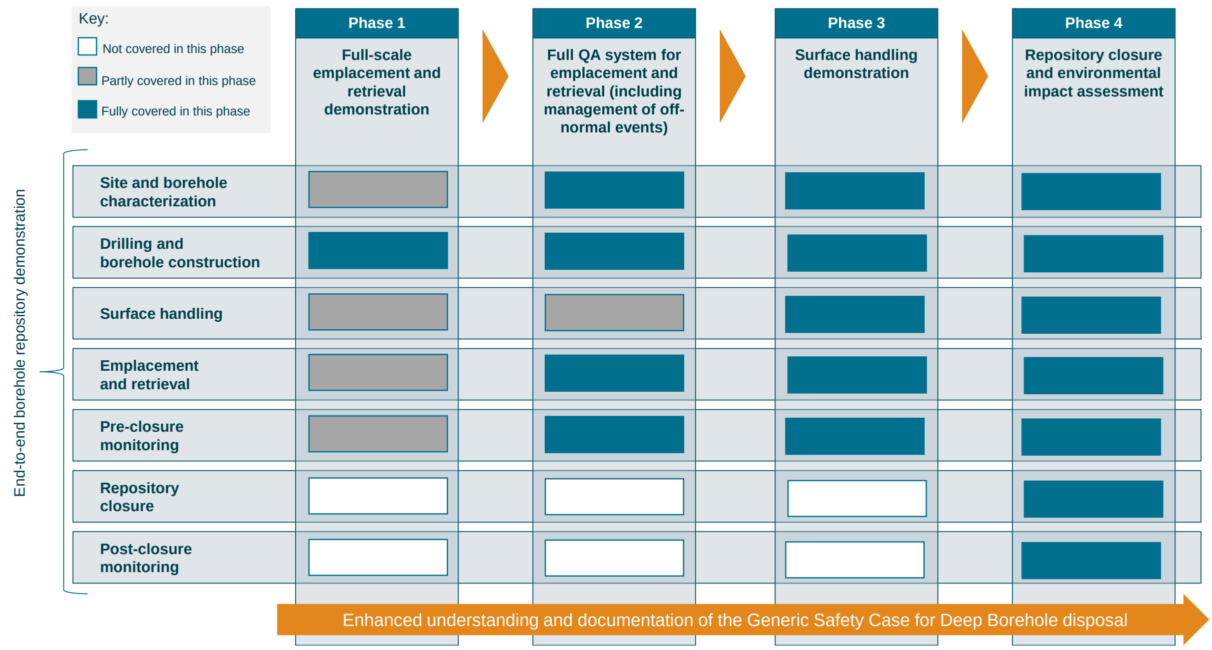
- **Policymakers, regulators and national Waste Management Organizations see deep borehole disposal as offering very significant potential benefits**, including:
  - ***Increased choice and siting flexibility*** for national disposal programs
  - ***Cost, risk and time reductions*** across such programs
  - Potentially attractive features from the perspective of ***community consent***
  - Potential for ***economies of scale around regulatory processes***.
- **Four-out-of-five government and regulatory stakeholders want more international collaboration to advance deep borehole disposal** - with the top two priorities being:
  - ***Demonstration:*** Establishing an end-to-end technical demonstration of an operational DBD repository.
  - ***Guidance:*** Using a demonstration as the focus for international collaboration to develop improved guidance and international consensus around how to demonstrate and document the safety case for DBD.

Following publication of this research in 2022, Deep Isolation led a process of consultation with international stakeholders on how to respond to this clear demand.

The result is the Deep Borehole Demonstration Center: a multi-national, public-private-partnership, nonprofit initiative that aims 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*."

The Center was established as a nonprofit organization in the State of Texas on 1 December 2022, and launched publicly on 27 February 2023 [14]. Its Strategic Plan [15] outlines a phased, prioritized program of work as illustrated below.

Exhibit 14: a phased approach to demonstrating the full repository lifecycle



5. Further information and next steps

If you wish to find out more about Deep Isolation, please:

- Visit our website at www.deepisolation.com. This provides a wide range of resources, including:
  - A video providing a five-minute overview of our horizontal borehole solution
  - White Papers describing our technology in more detail
  - Detailed safety calculations, describing the methodology, models and evidence used to demonstrate the generic post-closure safety case for Deep Isolation.
- Email us at emea@deepisolation.com with any comments or questions.

To find out more about the Deep Borehole Demonstration Center, please:

- Visit its website at www.deepboreholedemo.org
- Contact its Executive Launch Director, Ted Garrish at ted.garrish@deepboreholedemo.org.

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