

Deployment Readiness of the Universal Canister System for Deep Borehole Repositories – 26194

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ABSTRACT

The Universal Canister System (UCS), developed by Deep Isolation with support from the U.S. Department of Energy’s Advanced Research Projects Agency–Energy (ARPA-E), was conceived as an integrated waste management system to enable the safe storage, transport, and disposal in both conventional mined repositories and deep boreholes of a wide range of waste streams from legacy and advanced nuclear reactors. The UCS is intended to simplify back-end operations by providing a standardized, multi-functional waste package that can adapt to a variety of fuel types and waste forms. Over the past three years, the UCS has progressed from conceptual design to prototype fabrication, integrated repository safety and performance modeling, waste form testing, and the establishment of preliminary Waste Acceptance Criteria. These achievements confirmed the technical viability of the UCS and mark the conclusion of its initial development phase.

As the development program closes, the next step is to demonstrate UCS performance in a representative deep borehole repository environment, an urgent priority to sustain the momentum of advanced nuclear technologies and ensure that back-end solutions advance in parallel with reactor deployment. International stakeholder research has consistently concluded that a full-scale demonstration is essential to establish confidence in borehole disposal concepts, to validate models with empirical data, and to provide a sound basis for regulatory review. In 2023, governments, regulators, industry, and research organizations came together to define the attributes of such a demonstration with the goal of ensuring it produces data of international relevance, with key stakeholders collaborating to establish a multi-national, non-profit organization to drive forward such demonstration in a phased and prioritized way: the Deep Borehole Demonstration Center.

This paper synthesizes recent research and development outcomes, summarizes lessons learned from prior borehole demonstration planning activities, and discusses how the UCS can be integrated into a prototypic deep borehole test. It outlines broad objectives for a demonstration program, including prioritization of test program goals, consideration of surface storage/staging, handling and transfer operations, confirmation of safe downhole emplacement and retrieval (e.g., off-normal postulated situations), evaluation of thermal and corrosion performance under representative conditions, and assessment of long-term safety functions. The discussion also identifies general requirements, such as coordination with regulatory frameworks and approaches for stakeholder engagement. The emphasis remains on framing objectives and requirements in a general manner, to maintain flexibility for different implementation pathways.

By outlining the transition from development to demonstration, this work underscores the importance of testing through repeated and varied operations, thus establishing deployment readiness for the UCS. A successful demonstration would strengthen domestic and international confidence in deep borehole disposal, provide regulators and stakeholders with critical performance data, and demonstrate that disposal solutions can advance in parallel with the deployment of advanced reactors. In doing so, the UCS can serve as a foundational technology to enable deep borehole repositories as a credible, safe, and cost-effective component of the global nuclear fuel cycle. This progression represents a critical milestone in closing the gap between innovative waste package development and large-scale implementation of new disposal concepts.

INTRODUCTION

Over 600 commercial nuclear power plants have achieved criticality and generated power in the past 75 years [1]. Today, 416 nuclear power plants are operational around the globe, producing over 10% of the world's electrical power [1], [2]. Given advances in the scale and design of nuclear power plants, increased demand for clean energy to meet consumer and industrial needs [3], and pledges from over 100 countries to commit to nuclear expansion [4], the world's nuclear power output has the potential to triple by 2050 [5].

Despite this historic precedent and renewed appetite for nuclear power, no permanent solution for the spent nuclear fuel (SNF) and high-level radioactive waste (HLW) resulting from power generation and related processes has been implemented. Governments are increasingly emphasizing the need to address SNF and HLW solutions through actions such as the European Union's incentives for waste disposition strategies by 2050 [6] and U.S. Executive Order 14302 [7]. Deep geological disposal has long been considered the most suitable method for solving the waste challenge [8], and mined geologic repositories (MGRs) have since been considered the default approach. Since the 1980s, several countries have pursued an MGR for their SNF and HLW, and Finland is expected to begin operations of the world's first repository for SNF in 2026 [9]. Though this progress sets a blueprint for addressing the disposition of SNF and HLW, the process has involved a multi-generational schedule and multi-billion dollar budget, prompting some countries to also consider alternatives and how options compare for their particular inventories and constraints [10], [11]. One such alternative is deep borehole disposal.

Over the past few decades, deep borehole disposal has been extensively researched from a desktop perspective with promising studies on topics ranging from post-closure safety analyses [12], [13] to economic studies [14], [15], [16]. With increased confidence in the concept and recent iterations on the design of disposal canisters [17], deep borehole disposal appears ready for a demonstration of the technology [18], [19]. An end-to-end demonstration is a pivotal milestone for stakeholders interested in the possibility of deep borehole disposal as a complement or alternative to an MGR [20]. The first deep borehole disposal system demonstration is currently being planned, with the aim of emplacing a canister in a prototypic borehole by 2027 [21].

DISCUSSION

Objectives and Priorities of the Demonstration Program

A full-scale demonstration of the Universal Canister System (UCS) in a deep borehole repository will mark the first emplacement and retrieval of a waste package specifically designed for permanent disposal of SNF and HLW into a borehole of prototypic depth for a deep geologic repository. The first demonstration is expected to be a nonradioactive test, with a goal of validating the design of both the UCS canister, as well as the borehole architecture. Despite there being no radioactive material, special consideration should be taken to simulate anticipated repository scenarios using best industry practices for the handling of special nuclear material. Such a disciplined approach to the demonstration effort will foster an environment of nuclear safety practices.

The main objectives for a full-scale demonstration program are:

1. Demonstrating the feasibility of drilling a borehole using standard oil and gas industry drilling practices at a diameter to support the long-term storage and/or disposal of nuclear waste canisters (e.g., Deep Isolation's UCS).

2. Demonstrating the feasibility of using standard oil and gas industry directional drilling to construct a horizontal borehole in a suitable shale formation at a representative depth in an effort to validate assumptions used in existing safety calculations for deep borehole disposal of SNF and HLW [13].
3. Simulation of deep borehole repository operations using prototypic equipment, including emplacement of multiple waste disposal canisters into a borehole, retrieval of multiple waste disposal canisters from a borehole, surface handling and waste canister transfer operations, and evaluation of the consequences of off-normal repository scenarios.

Meeting these objectives will exhibit to community, industry, government, and regulatory stakeholders that deep borehole disposal of SNF and HLW using Deep Isolation’s UCS is a technically sound and viable waste management solution. The demonstration also affords the opportunity to obtain high fidelity data (e.g., temperature, pressure, site characterization) which can be used to validate computational performance and safety models, establishing a basis for regulatory review. Furthermore, such a program allows for the verification of the technical maturity and commercial viability of deep borehole disposal systems.

Planning is underway to execute a demonstration program in three phases. The first phase will encompass construction of a prototypic borehole (i.e., drilling and casing of a well), followed by execution of subsurface operations (i.e., emplacement and retrieval of one or more UCS canisters). The second phase will encompass repository surface handling operations (i.e., staging UCS canisters in lag storage, and handling and transfer of UCS canisters to the borehole). This phase will culminate with a full end-to-end demonstration which combines all surface handling and subsurface operations. The third phase will explore off-normal conditions and failure testing (e.g., canister drop tests). Throughout all three phases, procedures for repository operations will be iteratively refined to account for lessons learned.

During operations at a deep borehole repository, surface handling (i.e., receipt of waste packages and transfer to the borehole) is a precursor to subsurface emplacement. However, the design and fabrication of the surface handling equipment is expected to have a long lead time, potentially delaying the start of subsurface testing. Therefore, the first phase of the demonstration program will focus on subsurface handling and testing, followed by surface handling testing once equipment and procedures are fabricated and finalized, respectively. This phased plan is illustrated in Figure 1, focusing on only the first two phases. The actual scope of Phase 3 will be defined at a later date based on information obtained from Phases 1 and 2.

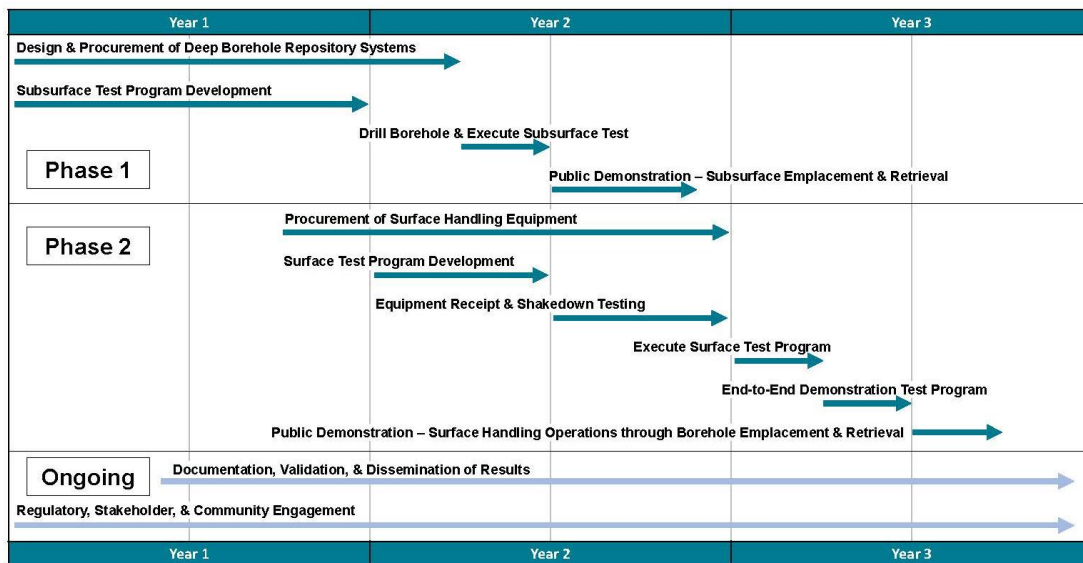


Figure 1. Full-scale demonstration Phase 1 and 2 tasks.

At all stages of the demonstration, maintaining operational safety will be the highest priority. Procedures will be detailed with enough rigor and quality assurance practices to meet codified nuclear standards, including initial conditions that must be met prior to advancing in a procedure as well as “go/no-go” milestones that only permit progression if tasks are completed with technical viability and assured safety. This will not only ensure safety is maintained for all personnel and equipment involved but will also serve as a starting point for developing a legitimate safety case for nuclear work. Testing will stop in the event of unforeseen circumstances that pose a danger to personnel or equipment and will only recommence when test leads have determined and agreed upon a safe and feasible solution for continuing.

Lessons Learned from Prior Demonstration Planning

In 2016, the U.S. Department of Energy (DOE) led a demonstration project with Sandia National Laboratories (SNL) to complete a deep borehole disposal test [22]. The Deep Borehole Field Test (DBFT) was planned as a two-part test to characterize boreholes in-situ during drilling and to demonstrate safe execution of surface and subsurface handling procedures, though extensive scoping details were only completed for the first objective. DOE and SNL planned to first drill a characterization borehole 3-5 km below surface into crystalline basement rock to demonstrate groundwater isolation from the biosphere. The scope included collection of fluid and rock samples and performance of hydraulic, mechanical, and geochemical tests with follow-on laboratory testing [22]. The project was cancelled in May 2017, with the DOE citing budget reprioritization [23].

Lessons learned from the DBFT are primarily related to the project planning stage. The ultimate closure of the project occurred only a year after the kickoff due to reallocation of funding, though a detailed strategic test plan for the characterization borehole portion of the project was published [24]. In addition to the lack of budget, under-communication between the project team, local government, and community stakeholders led to wariness among the public about the goals of the project. Many citizens in the area were uncomfortable with the idea of tests being performed for radioactive waste disposal, though the tests were nonradioactive in nature and ultimate disposal would be shown to be safe to the public [25]. Future demonstration efforts would benefit from extensive community outreach, education, and communication about the project and its goals, as well as extensive contingency budgeting during the planning stage.

In 2019, Deep Isolation demonstrated emplacement and retrieval of a canister sized for disposal of a CANDU (CANada Deuterium Uranium) fuel assembly or cesium/strontium capsule into an existing horizontal borehole at a drilling test facility [26]. This borehole extended to a total vertical depth of 2,000 feet, with a horizontal lateral section 400 feet long. The canister used for the test was designed to fit in an existing borehole and therefore was far smaller than canisters later developed by Deep Isolation. The 2019 demonstration successfully confirmed that a payload could be inserted into a horizontal borehole, released, and be retrieved at a later time.

Following development efforts for a canister designed for disposal of pressurized water reactor (PWR) SNF assemblies [27], [28], Deep Isolation and the Deep Borehole Demonstration Center (DBDC) conducted a test in 2023 to validate the design of the canister’s lift adapter assembly [29]. The canister and lift adapter were designed and fabricated in collaboration with NAC International, Inc. (NAC). The test successfully demonstrated the compatibility of Deep Isolation’s canister technology with standard oil and gas lifting equipment. Specifically, Deep Isolation utilized a GS Spear manufactured by Thru-Tubing Solutions [30] to engage with the UCS lift adapter assembly. Future demonstration efforts may consider design modification to the lift adapter to simplify operations, improve operational efficiency, and improve ease of engagement for retrievability.

The 2023 lift test highlighted the expected scale of the canisters to be used in actual disposal scenarios and successfully showcased that standard oil and gas industry equipment was compatible with the designed nuclear disposal equipment (Figure 2). The test identified a need for contingency plans in the event of unanticipated external factors, as well the need to plan for potential schedule delays. Severe weather caused several modifications to the existing plan – including delays due to loss of site power – and the incorporation of contingency strategies will benefit demonstration programs in the future.



Figure 2. Successful emplacement and retrieval demonstration of a full weight and size disposal canister in Cameron, Texas.

Integration of UCS into Prototypic Deep Borehole Test

The UCS was developed with the support of the U.S. DOE’s Advanced Research Projects Agency–Energy (ARPA-E) to accommodate a variety of advanced reactor and advanced fuel cycle waste streams, including vitrified waste canisters, TRISO (TRi-structural ISotropic) SNF, intact halide salt waste from molten salt reactors, and other waste produced as a result of reprocessing technologies [17], [31]. The UCS was also designed to meet a triple-purpose intention of an integrated waste management solution:

1. **Storage** at an Independent Spent Fuel Storage Installation located at a utility site or at a Consolidated Interim Storage Facility;
2. **Transportation** between waste generation or storage facilities and the repository; and
3. **Disposal** in a deep borehole disposal facility or MGR.

The canister design consists of a thick-walled shell assembly, welded closure lid and bottom plate, and a field-installed lift adapter assembly (lift adapter, key plate, cap plate, and jam plate) used for repository surface handling, emplacement, and retrieval operations [32]. To minimize the overall length of the UCS during storage and transport, the lift adapter assembly may be attached after receipt at the repository facility.

The UCS canister design also supports a family of canisters of multiple sizes (or classes) in varying diameters and shell thicknesses to accommodate a variety of waste forms, repository configurations, and disposal depths. The canister has a minimum design life of 360 years, assuming up to 60 years of storage (20 years for initial license plus 40 years for potential/anticipated license renewal) plus 300 years for disposal (containment required after permanent closure per Title 10 Code of Federal Regulations Part 60.113) [33]. All three classes share common, standardized features, including closure designs and

lifting attachments designed for interoperability with standard lifting and emplacement technologies used in the oil and gas industry.

The UCS is designed to be compatible with existing licensed storage and transportation casks sourced by NAC, particularly the MAGNASTOR® dry cask storage and MAGNATRAN® transport cask systems, respectively. These configurations may contain as many as 19 UCS canisters.

Integrating the UCS into a borehole demonstration program will help provide a valuable opportunity to validate the end-to-end functionality of both the canister design as well as the entirety of the borehole system. The UCS represents the key link between the various stages of a full borehole demonstration effort, including interim storage, off-site transportation, on-site transfer and surface handling, emplacement, downhole testing and monitoring as needed, and finally retrieval.

Testing of the UCS in a physical demonstration will also help enhance stakeholder, utility, regulator, and community confidence by allowing observation of practical deployment, handling, and retrieval of a disposal-ready canister. Demonstrating that commercial drilling technologies can safely and effectively manage the UCS builds trust in the system's reliability and transparency in the disposal process. By showcasing engineering rigor across all phases of the demonstration, the program will help provide visible evidence of the system's maturity and suitability for deep borehole disposal applications.

The demonstration program being planned will utilize multiple Class 1 UCS canisters for the duration of the testing. The canisters will be emplaced and retrieved from a deep borehole at prototypic depth (in a range of 1 km (3,280 ft) to 1.5 km (4,921 ft)) to verify proper functionality, robustness, and reliability of the surface handling equipment, as well as the engineered barrier system associated with the borehole repository. Repeated emplacement-retrieval cycles allow for progressive refinement of operational procedures, identification of potential design optimizations, and direct confirmation that the UCS interacts properly with repository equipment, can withstand downhole conditions, and can be properly retrieved without compromising canister integrity. Together, these processes ensure that the demonstration not only validates the design intent of the UCS but also provides a comprehensive basis for integrating the canister system into future commercial-scale borehole disposal efforts.

Downhole Emplacement and Retrieval Operations

Prior to commencing any repository testing involving a disposal canister, a prototypic horizontal borehole will be constructed. A vertical access shaft will be drilled, then curved slightly until a fully horizontal lateral is obtained at a total vertical depth between 1 and 1.5 km. The depth will depend on several parameters, including the site lithology and equipment capabilities. The horizontal waste disposal section in a final repository design will be optimized based on the inventory requiring disposal, but is expected to range from 1 to 1.5 km. For this demonstration program, the horizontal lateral is currently targeting 0.45 km (1,500 ft) to 0.6 km (2,000 ft). This shorter length is considered suitable based on the low inventory of UCSs that will be used for the test program.

Following completion of drilling operations, a carbon or low-alloy steel casing will be installed and cemented in place. Drilling and casing installation are planned in phases, such that a conductor casing will be installed at the surface of the borehole to assist in guiding the drilling process, surface casing will be installed from the surface to just below the aquifer depth to isolate the borehole from the water table, and production casing will be installed throughout the remainder of the borehole. Once casing installation is complete, any remaining drilling mud (fluid used while drilling to cool and lubricate the drill bit, stabilize the drillhole, and remove cuttings from the drill area) will be displaced with a low-salinity, water-based fluid to ensure the borehole is always fluid-filled, providing backpressure within the borehole for stability.

Once the UCS is secured at the wellhead¹, emplacement operations can commence. Planning is ongoing regarding the selection of equipment to conduct canister emplacement and retrieval operations. These operations may be performed using a coiled tubing (CT) rig, wireline and tractor, pulling unit, or drillpipe, depending on the final design of the repository and logistical considerations. A CT rig is comprised of a reel of tubing, gooseneck unit, injector drive motor, stripper assembly, and lubricator². Figure 3 illustrates an example of surface emplacement equipment using a CT rig.

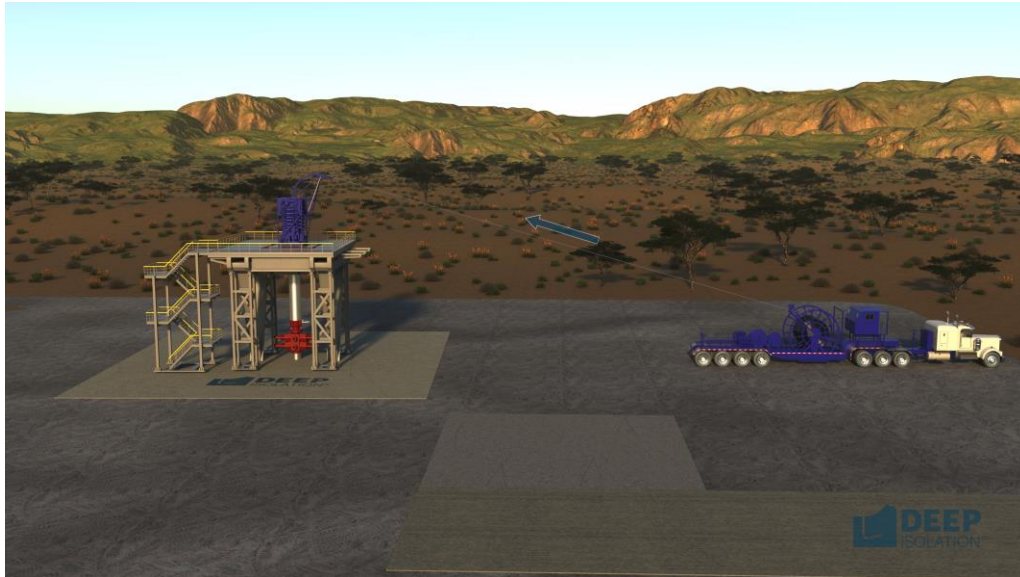


Figure 3. CT rig for use during canister emplacement operations.

An interface tool (e.g., GS spear) will be used to engage the UCS lift adapter, allowing for the UCS to be lowered into the borehole throughout the vertical, curved, and horizontal sections until its final position in the horizontal waste disposal section. The interface tool will then disengage from the lift adapter, and the CT, wireline, or drillpipe will be withdrawn from the borehole, leaving the canister behind. This evolution may be repeated to emplace multiple UCS canisters end-to-end within the waste disposal section.

Due to wide ranging requirements for retrievability of waste packages from deep geologic repositories, it is important to include retrievability in the scope of the test program. Retrieval of the canisters is expected to be a similar process to emplacement but executed in reverse. The interface tool – using CT, wireline, or drillpipe, along with centralizers as necessary – will be inserted into the borehole until it reaches the nearest UCS canister. The interface tool will latch onto the lift adapter and the entire stackup will be extracted out of the borehole. Once at the wellhead, the wellhead/lift adapter interface will be utilized to secure the UCS at the wellhead.

Sensors may be installed and used during the drilling process and subsequent test program to provide thermal, pressure, seismic, and/or radiation monitoring of the borehole at multiple locations, as well as in several areas around the surface of the repository. This data may be used for real-time indication of off-normal conditions and provide longer term operational monitoring for the lifetime of the repository. In addition, the emplacement rig may be equipped with force measurement (i.e., load) indicators, which will provide operators with positive indication as to whether the UCS is coupled with the interface tool. Safety

¹ During repository operations, the UCS will be transferred to the wellhead using surface handling equipment. During the first phase of the demonstration program, the UCS will be pre-staged at the wellhead using standard lifting and handling equipment.

² The gooseneck unit aligns and guides the coiled tubing from the spool into the borehole. The injector drive motor provides motive force to insert the tubing into the borehole. The stripper assembly serves as a pressure seal around the tubing, while the lubricator assembly acts as a pressure boundary/buffer between the borehole and the stripper.

will be prioritized throughout emplacement and retrieval operations. As such, procedures will be written and trained upon for off-normal and accident scenario response.

Surface Operations and Logistics

The surface portion of the simulated borehole repository will be comprised of the wellhead and a staging area. In the staging area at a functioning repository, the UCS canisters would be unpackaged from shipping casks and loaded into repository shielded overpacks (RSOs). The RSOs are envisioned as robust casks, similar to the MAGNASTOR®, constructed with reinforced concrete which provides shielding during staging and transfer to the borehole. A vertical cask transporter (VCT) may be used to move a loaded RSO from the staging area to the wellhead. Using a shielded indexer to ensure alignment with each UCS canister within the RSO, a dry transfer system (DTS) will be placed atop the RSO with a mobile crane. The DTS concept envisioned for this effort is similar to existing transfer systems commonly utilized by NAC and the broader nuclear industry for well over a decade, but will be adapted for compatibility with the dimensions of the UCS [34]. The DTS will use an internal hoist mechanism to extract a single UCS canister, maintaining shielding throughout the process, as illustrated in Figure 4. Once the DTS is loaded with a UCS, its bottom shield door will be closed, and the assembly will be transferred to the wellhead using the mobile crane. Once placed and aligned above the wellhead opening, the DTS shield door will open, and the internal hoist will lower the UCS into the top of the wellhead. Positive control of the UCS will then transfer from the DTS to the wellhead, where downhole emplacement operations will commence.

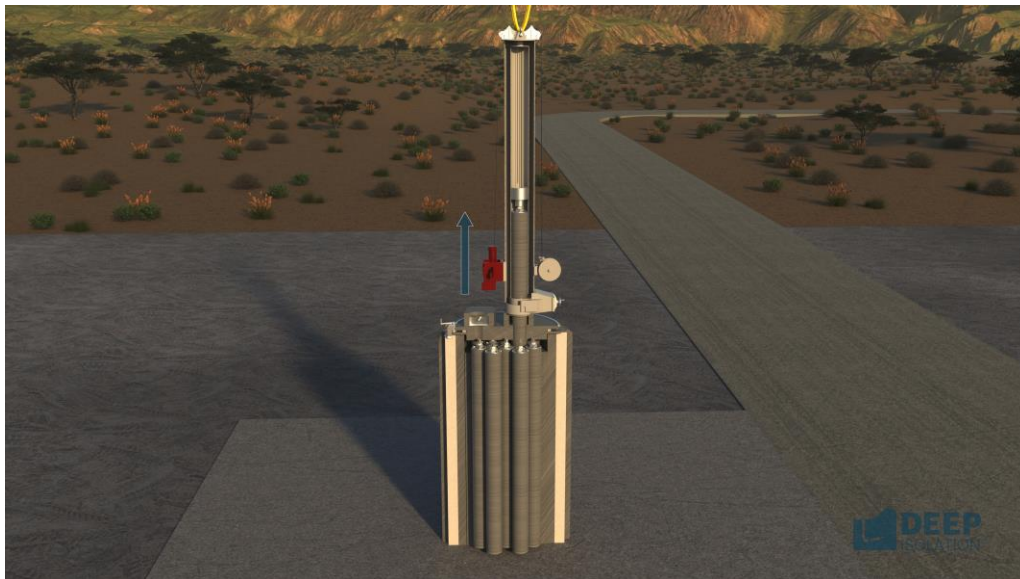


Figure 4. Mockup of DTS removing UCS from RSO.

All surface operations will be performed using standard SNF handling practices. Robust operational procedures will enhance safety controls throughout the surface transfer process. Contamination checks and general area radiation monitoring may be embedded into the procedures at key points, and continuous radiation monitoring equipment may be used to record data throughout the process. Integrating radiation monitoring checks into the procedures during the nonradioactive demonstration program will maintain operations as close to realistic as possible and allow for refinement of procedures that will eventually be used in disposal operations.

Evaluation of System Performance Under Repository Conditions

Empirical data for thermal, seismic, and material conditions of the borehole and canisters will be used to validate assumptions used in previous safety and performance assessments for deep borehole disposal. During the emplacement process, seismic sensors at the borehole and in the surrounding area can be used to measure disruptions from normal conditions. This will indicate any unexpected interactions between the engineering barrier system – the series of man-made components between the SNF/HLW and the environment (e.g., the UCS, the borehole casing, surrounding cement) – and the surrounding geology. Extensive drilling experience from partners suggests that this interface will be stable at the anticipated site, and that measured results will support these assessments or prompt additional research or changes in site evaluation models [35]. Ultimately, these measurements feed into performance assessment models for long-term repository stability.

The UCS canisters used in the demonstration will be loaded with a representative weight of potential waste cargoes. Heaters may also be incorporated into the test to simulate expected decay heat exhibited by SNF or HLW packages. Temperature and pressure sensors can be used to measure the temperature profile of the canister, the casing, and the borehole environment due to the combination of deep hydrostatic conditions and decay heat properties.

Following emplacement operations, non-destructive testing of at least one of the canisters may be conducted to evaluate its performance in the borehole. Depending on the length of time the canister remains in the borehole, such testing may include canister wear measurements to determine material resistance to friction, liquid penetrant testing to confirm the containment boundary (e.g., welds, walls) have not breached, or other evaluations. Similarly, internal borehole caliper measurements will be taken at various locations throughout the length of the casing. These measurements will serve to verify that the chemical and mechanical integrity of the UCS and borehole casing match the expected results from laboratory-scale testing and support long-term integrity assumptions [36].

Assessment of Long-Term Safety Functions

Deep Isolation has performed multiple safety and performance assessment calculations to support the development of the UCS and borehole repository design. These analyses have primarily been generic in nature, comprised of thermal performance models and radionuclide migration studies for generic repository configurations and lithologies [13], [37], [38]. The assessments illustrate the thermophysical effects on the canister and surrounding geosphere as a function of repository and waste form design, as well as estimate the peak radiological exposure dose to the public and timeframe for that to occur.

The preliminary assessments have been performed using models developed with randomly generated lithospheric compositions (varied within prespecified ranges) utilizing the iTOUGH2 simulation modeling software for fluid and radionuclide transport [39], [40]. Preliminary thermal performance calculations indicate that maximum temperature profiles across UCS canisters will remain within ranges that preclude a notable thermofluid driving head and should not detrimentally disturb the surrounding geology or damage the canisters [37]. Generic models indicate that the peak dose to the biosphere would occur at 1.6 million years after emplacement of PWR SNF assemblies in a horizontal borehole repository at a dosage three orders of magnitude below U.S. Environmental Protection Agency regulations for non-radiological workers³, which is illustrated in Figure 5 [13]. Additional models have been developed to explore the effects

³ The referenced generic post-closure safety model is based on a PWR SNF assembly in a generic waste canister. Recent work performed by Deep Isolation in the development of the UCS has tailored the model to UCS canister specifications and has analyzed performance for various advanced reactor waste forms.

of seals and plugs, variations in borehole geometries, corrosion and gas generation effects [41], and variations in geologic composition.

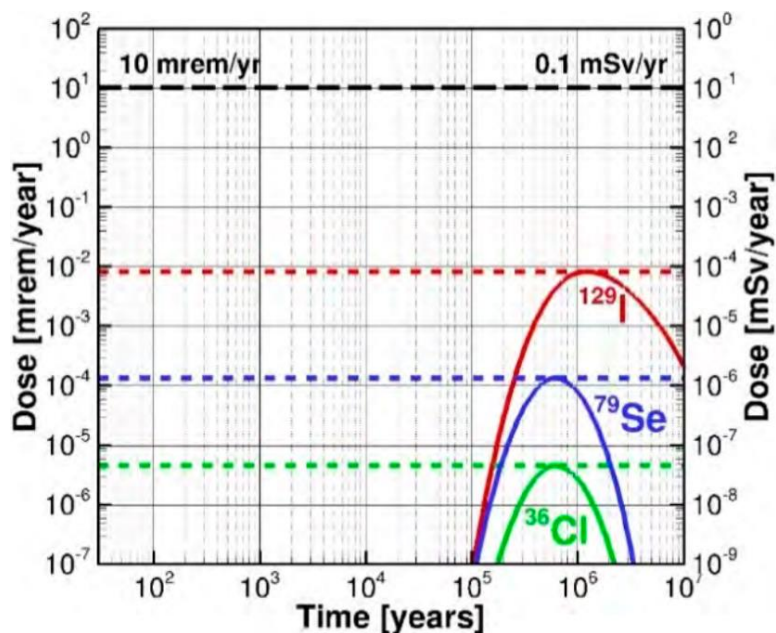


Figure 5. Generic horizontal borehole repository nominal scenario performance [13].

Performing a full-scale demonstration of deep borehole disposal will allow for the collection of data to support future preliminary siting efforts, validate assumptions of the performance assessment model, and enable development of a site-specific performance assessment model, if warranted. Several other variables, such as canister heat load, borehole fluid composition, and data from sensors, can be used to further refine post-closure modeling assumptions compared to those that have been used to date. Improved modeling fidelity may promote acceptance for a wider range of waste forms with less uncertainty regarding repository parameters and serve as the foundation of a comprehensive safety case.

Regulatory and Stakeholder Considerations

Coordination with regulators and public stakeholders is crucial to the success of any full-scale demonstration program. In addition to supply chain partners that will be participating in the demonstration, local, national, and international stakeholders will be involved in the planning and execution phases. Deep Isolation will work with the Deep Borehole Demonstration Center to coordinate efforts of engagement with the local community, offering education on the safety and long-term benefits of deep borehole disposal. Early and often communication with local stakeholders (both community and governmental) will enhance confidence and preclude misinformation about the project. Coordination with international stakeholders will also be incorporated into project plans to promote international applications for deep borehole disposal, further legitimizing the technology for global implementation. The transparent demonstration of the technology and associated safety results to these stakeholders will help pave the way towards regulatory adoption.

CONCLUSION

An end-to-end demonstration of deep borehole disposal is considered essential to validating the concept as a permanent solution to SNF and HLW management, and preparations for the first such a demonstration have begun. This nonradioactive demonstration program consists of three phases, with the opportunity to

complete the first two phases over a three-year period. Phase 1 will involve drilling and casing a prototypic test borehole and conducting emplacement and retrieval iterations for multiple prototype disposal canisters. Phase 2 will involve the design, procurement, and demonstration of surface handling equipment necessary to complete the transition from dry storage or transportation to deep borehole disposal. Whereas the first two phases will primarily replicate envisioned normal operations, Phase 3 will focus on off-normal events addressed in equipment and system design efforts but not yet tested at scale. The exact scope of this final phase will be informed by lessons learned and opportunities identified during the first two phases. All three phases of the demonstration are planned to occur at the Deep Borehole Demonstration Center, and local stakeholders are and will continue to be apprised of the status of nonradioactive borehole demonstration testing.

ACRONYMS

ARPA-E	Advanced Research Projects Agency–Energy
CANDU	CANada Deuterium Uranium
CT	Coiled Tubing
DBDC	Deep Borehole Demonstration Center
DBFT	Deep Borehole Field Test
DOE	Department of Energy
DTS	Dry Transfer System
HLW	High-Level Radioactive Waste
MGR	Mined Geologic Repository
NAC	NAC International Inc.
PWR	Pressurized Water Reactor
RSO	Repository Shielded Overpack
SNF	Spent Nuclear Fuel
SNL	Sandia National Laboratories
TRISO	TRi-structural ISOtropic
UCS	Universal Canister System
VCT	Vertical Cask Transporter

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