Deep Isolation-Development of the Safety Case for Disposal of Radioactive Wastes in Horizontal Boreholes – 20028

Rod Baltzer *, James Voss **, John Grimsich *
* Deep Isolation
** The Terra Verde Group

ABSTRACT

Deep Isolation has developed a safe, secure, and permanent geological disposal method for high-level waste, including spent nuclear fuel as well as sealed sources and other highly radioactive materials. The method leverages well established directional drilling technology to create horizontal repositories deep underground. The combination of great depth (1-3km) and the ability to precisely position repositories in a horizontal orientation provides access to geologic strata that are inaccessible for typical mined and deep vertical borehole repositories. A number of potential direct and indirect safety benefits accrue including :1) greater depth below regional freshwater aquifers; 2) increased flexibility and more geologic options for siting; 3) access to deep formations with persistent and sustained reducing conditions.

In addition there are a number of safety elements related specifically to the horizontal repository geometry including: 1) passive direction of thermally driven fluid and radionuclide movement away from the vertical access hole and toward the 'dead end' portion of the repository; 2) mitigation of seismic hazards by orienting repositories parallel to local and regional fault structures.

In this paper we explore and discuss some of the key technologic, geologic and hydrologic elements that support the deep horizontal borehole safety case.

The stalemate seen across the globe on the disposal of spent nuclear fuel and high-level waste can be broken. Deep Isolation offers a novel option for safe, secure, and permanent deep geological disposal of nuclear waste that can be developed as centralized repositories or adapted to smaller regional or site-specific repositories located near waste sources.

INTRODUCTION

Deep Isolation has developed a safe, secure, and permanent deep geological disposal method for high-level waste, including spent nuclear fuel as well as sealed sources and other highly radioactive materials. The method leverages well established directional drilling technology to create horizontal repositories deep underground. This approach builds on the geologic knowledge base and safety criteria developed over decades for other types of geologic repositories but provides additional flexibility in siting and offers safety features that are distinct.

DEEP HORIZONTAL DRILLHOLE TECHNOLOGY

Directional drilling is a mature and well-developed technology. The technology is used daily in the oil and gas industry globally with over 100,000 directional boreholes completed in the US and internationally [1]. Ongoing technological improvements have diminished risks associated with directional drilling, to the point that current state of the art technology provides the ability to drill holes with a diameter large enough (20 cm to 61cm) to dispose of many forms of nuclear waste in deep horizontal drillhole repositories far from the surface environment.

Deep horizontal drilling technology allows Deep Isolation to precisely place nuclear waste up to a few kilometers beneath the surface, well below surface aquifers, in carefully selected geologic formations. Repositories can be drilled and located with high positional precision. In the oil industry stacked parallel horizontal wells are commonly drilled with only several meter offsets over many kilometers, with maintenance of positional integrity [2]. In a multi-level vertically or horizontally distributed repository system, the placement and positional offset between repositories is limited more by considerations of future heat dissipation or hydrologic considerations than by drilling limitations. An additional benefit of horizontal drillhole repositories is that they can be oriented parallel to the dominant local and regional fault structures. This can help mitigate the effects of disruptive seismic events by decreasing the likelihood of cross-cutting fault movements that might breach the repository and create fast paths to the surface.

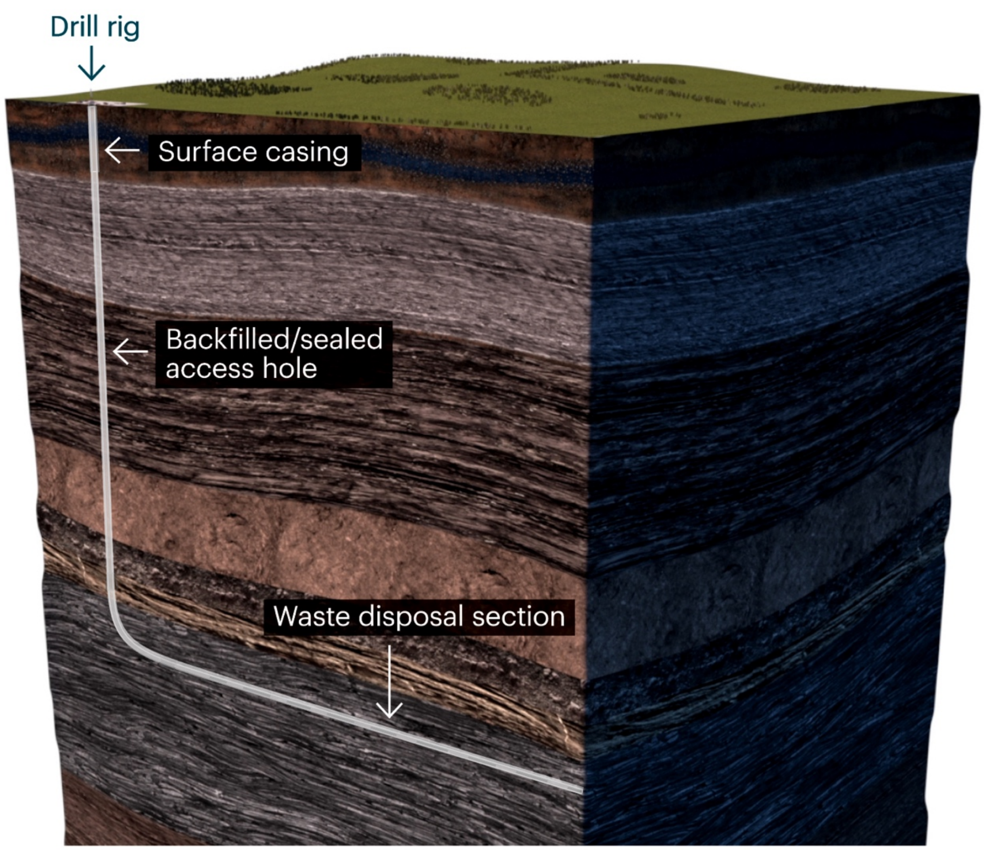

Figure 1: Schematic of the Deep Isolation Repository (not to scale)

SUITABLE GEOLOGY

The target geologic media for our disposal solution are formations that can demonstrate isolation from surface waters for millions of years. Potential repository formations include clay rich sedimentary strata (shales, clays, mudstones), as well as salt formations and crystalline basement rock types among others. These rock formations are present at various depths throughout much of the United States may be used for a repository environment after careful screening and testing. The depth of the repository and the layers of rock above it effectively isolate radioactive waste from the human accessible environment.

When selecting a repository site, it can be difficult to fully characterize the geologic and hydrologic complexity and model the long-term performance of the system. In addition to considering variability in fundamental rock properties (porosity, hydraulic conductivity, sorption capacity, fractures, etc.) one must also consider potential disruptive events (seismicity, overpressures) that may occur periodically and impact repository performance. These types of episodic events can be difficult to predict and their effects difficult to model with certainty. Because of this in addition to modeling efforts, we seek direct evidence of the past isolation of the repository environment through analysis of isotopic markers in pore water brines.

The absence of surface water isotopic markers and the retention and accumulation of mobile isotopes formed at depth can provide a long-term record of the isolative capacity of the formation. A number of different isotopic markers can be utilized including: Kr-81 as a marker for surface water intrusion over 1Ma timeframes; Cl-36 as a marker for the stagnancy and immobility of pore water brines for 1.5Ma time frames [3]; the retention of Helium, Neon and a number of other noble gases which accumulate in the subsurface as a result of natural Uranium and Thorium decay. Noble gas accumulation rates and isotopic ratios in particular can provide direct evidence for the isolation and retentive capacity of the deep geologic environment for tens to hundreds of millions of years over regional scales [4]. We consider direct evidence of past isolation to be an important indicator of repository suitability as it records the long term hydrologic response of the formation to tectonic and surface events (including climate changes, seismicity, and other unforeseen disturbances to the system) that have occurred over the past million years and longer. We believe this evidence of past performance is a critical piece in developing a strong safety case and increasing public confidence in deep horizontal borehole repositories and geologic repositories in general.

There is significant evidence that density stratified brines occur in many sedimentary and crystalline rock formations deep below surface aquifers, and that this stratification is persistent and durable over very long time (tens to hundreds of million year) frames [5]. In Canada noble gas data indicate crystalline basement rocks at 1.5-2.5 km depth have retained noble gases in fracture fluids for time frames from 100Ma to 1Ga[3] [6]. In Finland, fluids in crystalline basement rocks below 1 km are estimated to have been isolated for 20-50Ma based on noble gas accumulations [7]. This isolation is demonstrated despite varied and complex geology with intersecting fracture networks, and it seems to be regional in character. Deep Isolation technology is well suited to access these deep rock strata.

ENGINEERED BARRIERS

Deep Isolation is mindful of regulatory requirements for engineered barriers as well as the cases for exemptions under 10CFR60. Specially designed disposal canister materials are being considered, tailored to the geologic environments and geochemical conditions encountered in the disposal section. In addition, Deep Isolation is evaluating various backfill and seal materials that would be used to close the disposal boreholes. Seal types developed by U.S. national labs and underground research labs around the world include bentonite clays, cements, asphaltic compounds, and various rock forms used in combination [8].

There is a significant safety benefit that stems from reducing conditions expected in the formations in which Deep Isolation repositories will be situated. These environments are deep below the saturated zone, very low in oxygen, and should sustain reducing conditions over long time frames. This provides a corrosion environment that may be simpler and more predictable than in nearer surface mined repositories which may also need to consider periodic episodes of freshwater intrusion (e.g. resulting from glacial cycles) [9]. Reducing conditions are particularly beneficial for the durability of some engineered barriers, in particular uranium dioxide fuels from commercial reactors. In reducing conditions, the dissolution of uranium dioxide and consonant release of radionuclides can take from ~300,000 to several million years [10,11]. The expectation of stable long-term reducing conditions also informs the selection of alloys to be used in disposal canisters. At present we have selected and modeled a nickel-chrome-moly alloy for a disposal zone for a stable reducing environment. Our modeling suggests that 1-cm of the alloy can provide protection from passive corrosion for up to 40,000 years [12]. This exceeds the requirement in the US for an engineered barrier of 300 years.

DISPOSAL METHOD

In a Deep Isolation repository, waste forms are first encapsulated in disposal canisters and the canisters are then lowered and placed in the horizontal drillhole repository in an end-to-end configuration. The repository and canisters are designed with near-term retrievability of 50 years, a regulation requirement in some countries including in the United States [13], using standard and well-established drilling emplacement and retrieval technologies. Drillhole repositories of different sizes can be built in a modular fashion, tailored to the specific waste inventories as well as geographic and geologic conditions. This makes the horizontal disposal solution ideal for countries with smaller waste inventories or for situations where transportation of the nuclear waste offsite to another location is not desirable.

ELIMINATION OF PATHWAYS

In all disposal concepts, the process of emplacing nuclear wastes creates pathways for its release to the biosphere. One of the principal pathways is along the access hole needed to place waste underground. Though robust layered engineered barriers have been developed to mitigate this pathway, it remains a concern [10,11]. One way Deep Isolation minimizes this migration pathway in its repositories is by the design of an inclined horizontal emplacement section which extends a considerable distance from the vertical access borehole. The slight inclination of the emplacement section by a few degrees directs potential thermally driven migration of nuclides upward toward the 'dead end' section of the repository, and away from man-made engineered barriers. Initial analyses of commercial PWR fuel indicate that during the period of greatest thermal excursion in the repository no excess thermal gradient in the vertical access hole develops, thus eliminating an energy source to move contaminants to the surface [14]. This simple passive system is operative throughout the lifetime of the repository and directs thermally driven fluids and radionuclides away from the vertical access pathway and toward the geologic strata which is the primary safety barrier. Analyses modeling the effects of gas generation and fluid migration in the repository are ongoing.

SAFETY CASE

A detailed safety case involves thorough analysis and modeling of the host rock formations, subsurface chemistry, evolution, and degradation of the waste form and transport mechanisms that might lead to the migration of radionuclides over very long timeframes. A series of features, events, and processes (FEPs) are analyzed in detailed statistical analysis to develop a probabilistic safety assessment. These analyses are common to all geologic repository studies.

A comprehensive safety analysis is being prepared by Deep Isolation. Our initial investigation and modeling of a 1km deep horizontal drillhole repository in a generic shale formation situated beneath surface aquifers produces a peak annual dose well below the statutory standard of 15mrem per year. Each Safety case will be site specific, however this initial effort suggests that a properly sited, constructed, and sealed Deep Isolation repository will provide a safety for the public over 1Ma time frames. Human intrusion (direct disruption of the repository) is a factor that must be considered for all repository types. The most probable mechanism for intrusion involves the extraction of natural resources from the repository site at some future date. Minimization of this probability is primarily a function of site selection. However, deep horizontal drillhole repositories offer significant reduction in intrusion likelihood due both to their depth (1-3km) and their small (20-61cm) cross section.

CONCLUSION

The stalemate seen across the globe on the disposal of spent nuclear fuel and high-level waste can be broken. Deep Isolation offers options for safe, secure, and permanent deep geological disposal of nuclear waste. This option provides safety in depth, flexibility in siting, and a modular approach to waste disposal that can be adapted to small scale local repositories or large regional repositories

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