The Deep Borehole Disposal Method and an International Demonstration Project Proposal for Australia – 24330

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ABSTRACT

Deep borehole disposal (DBD) is a promising concept for the safe and long-term disposal of radioactive waste. This paper presents a proposal for a demonstration project located in Western Australia, highlighting the potential of the concept as a viable solution for the management of radioactive waste; this is in context of Tellus Holdings (Tellus) receiving indigenous approval for a DBD project and finalizing development approvals to start this project in connection with its proposed research collaborator the Australian National University (ANU).

DBD involves the emplacement of waste in deep, stable geological formations, providing multiple barriers for containment and isolation. By utilizing the geological stability and impermeability of deep boreholes, DBD offers enhanced safety and security while minimizing environmental impact.

The proposed demonstration project aims to assess the feasibility of DBD in the Australian context. Western Australia possesses geological conditions likely to be suitable for deep borehole disposal, making it an ideal location for this demonstration.

The project includes three key components: site selection, engineering design and comprehensive safety analysis. Site selection involves geological surveys to identify appropriate rock formations capable of providing sufficient isolation and containment. Engineering design focuses on borehole construction, waste emplacement, and monitoring systems, ensuring the integrity and stability of the disposal system. The safety analysis includes risk assessment, long-term performance evaluation, and contingency planning. The demonstration project will serve as a valuable opportunity to engage stakeholders and the public, fostering transparency and addressing concerns related to waste disposal. It will provide valuable insights into the technical, environmental, and socio-economic aspects of implementing DBD, enabling informed decision-making for future management strategies and waste management initiatives in the country.

Furthermore, this project will contribute to the broader international dialogue on safe and sustainable disposal options for radioactive waste, promoting knowledge sharing and collaboration. The DBD concept, with its inherent safety features and potential for deep geological isolation, offers a promising approach to addressing the challenges of radioactive waste management. The paper outlines the deep borehole disposal concept and presents a proposal for a demonstration project in Western Australia, demonstrating the feasibility and potential of DBD as a long-term solution for the safe disposal of radioactive waste.

INTRODUCTION

In broad terms, radioactive wastes fall into two categories – wastes that can be contained in near surface repositories and wastes that need to be isolated for very long periods of time in suitable geological formations. Tellus has developed a state-of-the-art near surface repository for hazardous and low-level radioactive wastes (LLW) which can be safely isolated given consideration to the natural and engineered barriers at the facility. The Sandy Ridge facility is in Western Australia and is fully operational following extensive safety evaluation and stakeholder consultation.

Tellus has permitted a deep borehole within its property in Western Australia to support ongoing Australian and international research and development for the disposal of certain long-lived radioactive wastes that require a long isolation period. This facility, once funded and developed, will be used for scientific and engineering development, but will not involve the disposal of any radioactive wastes.

THE PROPOSED SITE

Tellus proposes to undertake an international DBD testing program on its property near Sandy Ridge, Western Australia. The Sandy Ridge facility is a fully permitted management and disposal facility for hazardous and low-level radioactive wastes. The management approach is shallow burial in the kaolin clays present at the site. The Facility is intentionally located in a remote, geologically stable, un-populated and semi-arid area and applies world's best practice standards focusing on long term environmental and human safety as the primary criteria for operational and post-closure risk assessments.

Key characteristics of the Sandy Ridge site are:
- Well-established social licence to operate through relationships with traditional owners and the local community.
- Geologically stable.
- Natural geological barrier provided by kaolin clay.
- Semi-arid climate with very low average annual rainfall and very high evaporation rates.
- No nearby surface water or groundwater receptors.
- No significant surface water runoff.
- Lack of commercial mineral deposits.
- Flat topography.
- Absence of population.
- No medium to high value agricultural land use.
- No Environmentally Sensitive Areas or Matters of National Environment Significance.
- No rare or threatened flora or fauna habitats.
- No significant surface and ground water features.
- No identified areas of special cultural or historical significance.
- No flooding and very low risk of cyclonic impacts.
- Very low rates of erosion.

AUSTRALIAN IMPERATIVE FOR DBD

There are several reasons why Australia needs and benefits from the development of a safe DBD system for long-lived wastes. The dominant rationale, connecting to each specific potential application, is clearly stated in the position statement issued by International Association for Environmentally Safe Disposal of Radioactive Materials (EDRAM) in April 2022 [1]:

> *DBD may have potential as an alternative to deep geological repositories (DGRs) for countries with small waste inventories for which DGR is not a logical or economically viable solution. However, it would still only be suitable for wastes which can be easily converted to small diameter packages.*

Domestic waste management

Australia possesses small quantities of long-lived wastes derived from the reprocessing of the HIFAR nuclear reactor fuel.[1]

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[1] HIFAR spent fuel was reprocessed in Europe and the UK with certain long-lived wastes being the final responsibility of Australia.

In the future, similar wastes will result from the management of the spent fuel from the OPAL reactor. This waste will likely require disposal in a deep geological setting. DBD is one option and is considered to deliver safe management results at a considerably lower cost than other solutions.

Australia, the United Kingdom and the United States Security Partnership (AUKUS)[2]

Under the AUKUS agreements, Australia will become the owner of nuclear-powered submarines. Responsibility for disposal of spent nuclear fuel from the submarine reactors (or resulting high-level wastes if the fuel is reprocessed) is expected to remain with Australia. The proof of the ability of DBD to deliver this solution could support the strategic deployment of nuclear-powered submarines.

Carbon dioxide reduction

It is believed that DBD can provide a safe solution for long-lived waste management at a significantly lower cost than other approaches. Proving this may enhance the attractiveness of nuclear power in countries that otherwise would have very little long-lived wastes. This creates an additional opportunity for the reduction of carbon dioxide emissions by replacing fossil fuel generation with nuclear. The benefits of this will accrue to many people around the world including Australians who are impacted by anthropogenic climate change.

Global responsibility

Australia supplies around 10 per cent of the world’s uranium used, predominantly, for the generation of electricity. The generation of electricity with uranium fuel results in long-lived radioactive wastes which require long-term deep disposal. While some national buyers of Australia uranium have ongoing disposal programmes for disposal of long-lived radioactive wastes, this is not the case for all recipients. Developing DBD technology could enable Australia to assist countries that have purchased Australian uranium but have no disposal path for long-term disposal.

Support of Waigani and Association of Southeast Asian Nations (ASEAN)

The proof of the DBD system can assist Australia to fulfil its obligations to neighbours who are signatories to the Waigani Convention, as well as ASEAN members. Nearly every nation generates radioactive wastes including sealed sources. Many nations in the region lack the geosphere that is appropriate for near-surface disposal of radioactive wastes. Many, however, possess geology that may be suitable for DBD.

The *Convention to Ban the Importation into Forum Island Countries of Hazardous and Radioactive Wastes and to Control the Transboundary Movement and Management of Hazardous Wastes within the South Pacific Region (Waigani Convention)* entered into force 21 October 2001.

The Waigani Convention:

- bans the import of all hazardous and radioactive wastes into South Pacific Islands Forum countries that have agreed to the Waigani Convention.
- allows Australia to receive hazardous wastes exported from Pacific Islands Forum countries that have agreed to the Waigani Convention, and
- Australia ratified the Waigani Convention in 1998.

The Waigani Convention includes the following countries:

- Cook Islands
- Federated States of Micronesia
- Fiji
- Kiribati

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[2] Joint Leaders Statement On AUKUS | Prime Minister of Australia (pm.gov.au)

- Nauru[3]
- New Zealand
- Niue
- Palau[2]
- Papua New Guinea
- Samoa
- Solomon Islands
- Tonga
- Tuvalu

Australia sees ASEAN at the centre of a stable, peaceful, prosperous and secure region, where all states contribute to a strategic equilibrium. ASEAN is of profound significance for Australia's future, and our strong relations reflect close to half a century of cooperation. Australia became ASEAN's first Dialogue Partner in 1974. Australia strongly supports the principles of the ASEAN Outlook on the Indo-Pacific (AOIP).

ASEAN is a key trading partner for Australia. In 2021, Australia's trade with ASEAN countries was $127.1 billion, which is greater than our two-way trade with Japan and the United States. Our two-way investment with ASEAN in 2021 was $248.7 billion.

In October 2021, ASEAN and Australia made the historic decision to establish a Comprehensive Strategic Partnership (CSP). The CSP includes funding of projects jointly identified by ASEAN and Australia in the areas of energy security, protecting oceans and building circular economies.

Through the ASEAN Socio Cultural Community Blueprint 2025, Australia collaborates with ASEAN collective efforts in environmental protection through policy dialogue and harmonisation, research, capacity building, technical assistance, scaling up and replication of good practices across ASEAN countries. These efforts include collaboration on disposal of wastes using global best practices.

The ASEAN member countries are as follows:
- Brunei
- Burma (Myanmar)
- Cambodia
- Timor-Leste
- Indonesia
- Laos
- Malaysia
- The Philippines
- Singapore
- Thailand
- Vietnam

DEEP BOREHOLE DISPOSAL

Extensive work has been done across the globe for the engineering, safety and science of DBD. A comprehensive report was published by the Sandia National Laboratories in 2016 [2]. This report presented the graphic below (Figure 1) to explain the DBD approach.

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[3] Signed but not ratified.

Over the last few years, the concept has been adapted by various organisations and repository programmes to the respective geological conditions and the different waste inventories. Due to this several different borehole designs can be found in the literature. However, the general idea of the DBD concept is the same.

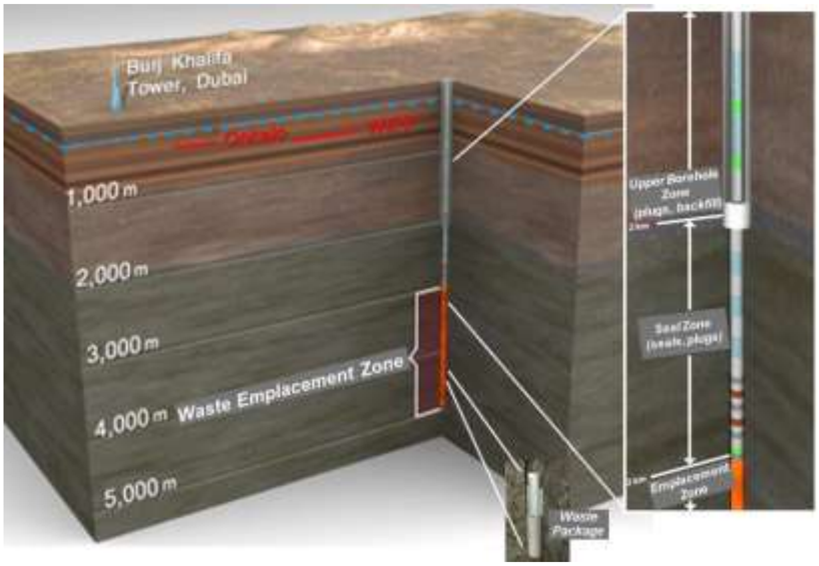

Figure 1. Artist’s concept of DBD [2].

The DBD system involves the emplacement of radioactive wastes in a borehole that might be up to 5 km in depth. In most approaches, only high-level and/or long-lived waste is considered for DBD. Wastes are placed at the lower portion of the borehole. As in other waste disposal concepts, waste packages are used in DBD as well, even though the packages do not necessarily contribute to the further isolation of the radioactive inventory. However, the waste packages represent an additional engineered barrier. The main task of the waste packages is to ensure a safe disposal at the desired depth in the borehole. After the emplacement of the waste packages, sealing systems are installed above the packages to seal the borehole.

As the previous paragraph implies, the safety concept relies on the natural barrier of the geological environment. In some concepts, waste packages and the sealing system are considered to be part of the safety concept as well. The waste packages and borehole sealing systems are generally described as engineered barriers. An example was presented by Doblin et al [3] and is slightly adapted presented in Figure 2 below.

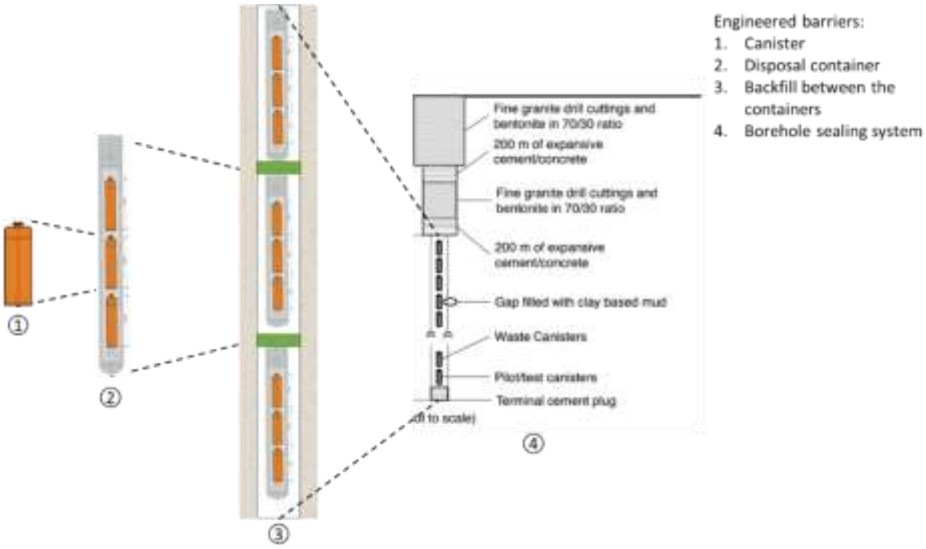

Figure 2. Schematic of the engineered barriers for a DBD concept (modified from [3].).

However, in any case the formation is the most important and central part of the safety concept. Therefore, during the site selection process proving the geologic stability of the host formation is of special importance. Possible movement of the rock body must be ruled out as far as possible, as this could not only damage the waste package, but also create possible flow paths to the surface environment. Furthermore, the absence of vertical and lateral water flow from and within the emplacement horizon should be ensured. In principle, any continuous fractures or fissures within the formation can be potential flow paths for a radionuclide transport. Due to this fact, the sealing of the borehole plays a decisive role, since the borehole itself will represent the direct flow path from the waste to the environment.

When it comes to the technical implementation of a DBD project, several design related parameters need to be considered and kept in mind. Many of these parameters are related to each other. The most important parameters as well as their connection are displayed in Figure 3.

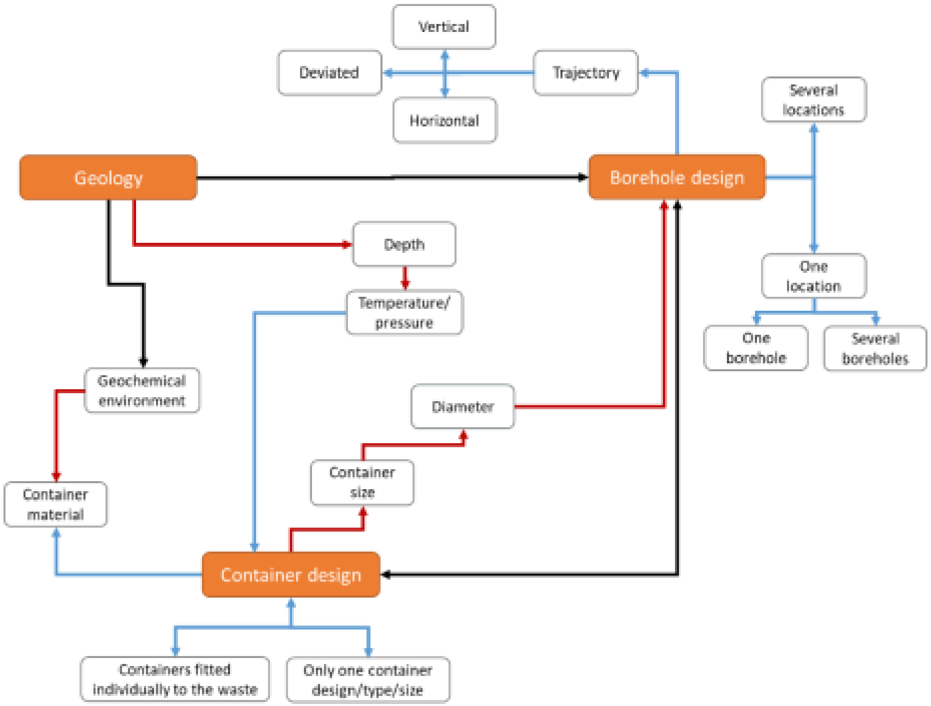

Figure 3. Most important parameters for the development of a DBD concept and the relations between each other [4] .

Some of the presented parameters will be discussed in more detail within the next paragraphs. One of the first decisions to be made, when it comes to the general design of the disposal borehole, is the trajectory of the borehole. Here either horizontal, deviated or straight vertical holes are the potential options that have been considered.

Horizontal boreholes are being explored as a viable concept for the storage of multiple disposal canisters within a unified borehole structure [5], characterized by the presence of Christmas-tree-like junctions embedded within a geologically suitable host rock. Nevertheless, despite its increasing adoption within the domain of oil and gas drilling operations, this methodology presents an array of formidable challenges when applied to large-diameter disposal boreholes. Firstly, the diameter of disposal boreholes exceeds the conventional dimensions commonly encountered in oil and gas drilling, necessitating the utilization of a less pliable and more operationally intricate large-diameter drill string to accommodate the disposal canisters. This deviation from standard horizontal borehole practices engenders dynamic stresses on the drill string during rotation within deflected borehole sections, thereby diminishing the safety margin of the constituent materials. Moreover, maintaining precise control over borehole trajectory, particularly when employing the preferred air hammer drilling technique, poses a formidable challenge. The emplacement process in a horizontal borehole introduces added complexities, as gravitational forces compel the canister to descend towards the lowermost region of the borehole cross-section, where residual cuttings and drilling fluid tend to accumulate. This gives rise to an abrasive milieu that may cause unpredictable wear on the exterior of the canister. Additionally, close proximity to the borehole wall introduces the prospect of differential sticking problems, with the potential for canister entrapment in cases where borehole pressure exceeds the local rock pore pressure, leading to potential impediments midway along the intended disposal route. Achieving an effective seal within a horizontal borehole represents yet another challenging endeavour, mandating precise placement of packers within the horizontal section to forestall the onset of leakage or undesirable material migration [4]. In summation, these formidable challenges overshadow the perceived benefits of horizontal wells for a DBD project.

It is thus clear that the need for careful consideration and formulation of proactive mitigation strategies is underlined before embarking on this unconventional approach. A vertical well is generally easier to drill. During the emplacement process and plugging of the well, the vertical option also holds some advantages. Due to the challenges associated with horizontal boreholes, both during drilling and during operation, vertical borehole paths are favored, especially when considering large-caliber boreholes.

A pivotal factor influencing borehole dimensions resides in the nature of the waste inventory to be accommodated. The inventory's compatibility with the canister is paramount, wherein the largest inventory component that cannot undergo subdivision dictates the minimum dimensions of the disposal canister. A canister primarily designated for waste transportation to the disposal zone may feature a diminished wall thickness, in contrast to a canister integrated within the barrier system, necessitating a heightened wall thickness owing to corrosion considerations. Moreover, the load attachment point assumes the responsibility of supporting the weight of the waste, alongside the augmented material mass. Consequently, this may introduce further ramifications for dimensional considerations. As mentioned earlier, the borehole diameter is contingent upon the canister's dimensions. The canister requires a specific clearance to traverse the borehole devoid of entanglement risks. Notably, deviations in the borehole trajectory and caliper, arising from the wear and tear of the drill bit, necessitate careful consideration in this context. Should the host rock necessitate casing to uphold borehole integrity, additional spatial requirements must be factored in, taking into account the requisite clearance between the casing and the borehole wall [6].

Besides the borehole diameter, the borehole depth is one of the central aspects, which needs to be brought up, especially when keeping the safety concept (which is mainly based on the formation) in mind. Not only due to this, is the borehole depth of special interest. Maximizing borehole depth within the constraints of available machinery is imperative to optimize disposal capacity. The foremost limiting factor for borehole depth often pertains to the hook load capacity of the drilling rig. Correspondingly, alongside the augmentation of borehole diameter, the weight of the drill string or casing escalates substantially, surpassing the capabilities of conventional drilling rigs. Even high-capacity rigs boasting a 1,000 metric ton hook load approach their operational limits when tasked with handling thin-walled 700 mm diameter casing of approximately 3,000 meters in length. A well-established and dependable technique for drilling large-diameter holes in granite host rock formations is the employment of the air hammer drilling method. Nevertheless, it is pertinent to note that this method is presently primarily employed in shallow wells or during the initial casing stage of conventional boreholes. Nonetheless, it merits consideration for its potential to generate a vertically aligned borehole with commendable quality and minimal deflection in the drilling trajectory.

After the design and construction of the disposal borehole comes the operational phase. Here the emplacement techniques come to play. Currently the applications for the emplacement in DBD concepts are only in an initial conceptual phase, however each of these techniques having undergone testing or application in other contexts. A critical imperative lies in the validation of these concepts within real-world DBD scenarios. Notably, five principal techniques can be elucidated [7]:

- Freefall (cannot be controlled, which makes this option unfeasible and is therefore not considered).
- Wireline.
- Use of drill pipes/drill string.
- Use of coiled tubing systems.
- Conveyance liner.

The final step after emplacement of the waste may be the most important step when considering long term outcomes. The borehole sealing represents an engineering barrier pivotal to prevent migration of radionuclides from the host rock into the geosphere via the excavated borehole.

This objective is realized through the meticulous restoration of the host rock's integrity to the greatest extent technically feasible. While sealing large boreholes within mining environments constitutes a well-established practice, the sealing of a deep borehole repository presents a distinct challenge, hitherto untested in practical scenarios. Materials such as clay, bitumen, and cement-based compounds are of primary consideration. Additionally, noteworthy are emerging geopolymers, which exhibit promising attributes for sealing applications in the context of DBD [8].

NEED FOR A FIELD TEST

A full-scale field test is needed to develop logistics and advance the technical basis for the siting and implementation of a DBD facility. The overall goal of a field test is to demonstrate and evaluate technologies necessary for determining the safety and feasibility of the DBD concept, but without the use or disposal of actual radioactive waste, where testing would be focused on the following objectives:

- Demonstration of drilling technology and borehole construction to 5,000 m depth in crystalline basement rock with sufficient diameter for cost-effective waste disposal.
- Evaluation of downhole scientific analyses to characterize the thermal-hydrologic-chemical-mechanical (THCM) conditions at a representative location that control waste stability and containment.
- Evaluation of package and seal materials at representative temperature, pressure, salinity, and geochemical conditions.
- Development and testing of engineering methods for test package loading, shielded surface operations, and test package emplacement and retrieval.
- Development and testing of sealing designs and seal emplacement methods.
- Demonstration of pre-closure and post-closure safety.
- Demonstration of waste package emplacement.

All over the world, many different organizations and radioactive waste management programs consider deep boreholes as a potential solution for the disposal of radioactive waste (e.g. NND [4] [8], ARAO, Dansk Decommissioning, ERDO [9], Israel [10]). This option is especially promising for countries with small inventories. Currently the most advanced option, disposal in deep geological mines (DGRs), is potentially more cost intensive and difficult to present from a cost-benefit perspective. In Europe, for example, smaller programs have joined forces to pool resources and explore different possibilities when it comes to the disposal of radioactive waste. On the ERDO committee, DBD is a topic of discussion and research is continuously ongoing. However, to convince individual national governments, a demonstration test is necessary. A successful demonstration of the required drilling campaign, including emplacement tests etc., could free up further resources for research and development.

CONSULTATION

Tellus maintains direct and open relationships with all stakeholders in the region. These relationships have been established and maintained through many years of consistent engagement. While a DBD experimental program does not involve any hazardous or radioactive materials, Tellus has engaged with key stakeholders to explain the concept and the nature of the anticipated work.

CONCLUSION AND NEXT STEPS

Tellus is proceeding with the next steps to enable this project to commence:

- Approvals: Tellus will continue to work with all regulatory authorities to comply with approvals for the DBD testing program.
- Partnerships: Tellus will seek to form testing partnerships throughout the region and the world.

The ability to fully demonstrate the concept and provide key engineering and environmental information will directly benefit all participants.

- Consultation: Throughout the execution of the future steps, Tellus will continue to have full and open dialogue and consultation with all stakeholders.

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