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Feature

Looking down the bore

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Deep borehole waste disposition research has not progressed to demonstration. Fergus Gibb reviews the steps necessary before drilling can begin.

Historically, reluctance to pursue deep borehole disposition centred on the fact that, while boreholes a few metres in diameter were possible and holes could be drilled to depths in excess of 10 km, the combination of a hole several tens of cm in diameter to a depth of 4 km or more has never been attempted (largely because the hydrocarbon, geothermal energy and other industries have had no need for it.) This gave rise to allegations of "immature technology" and concerns that to develop the necessary capability could take many years and prove prohibitively expensive or even impossible.

In 2000 SKB commissioned a feasibility study [14] into drilling the boreholes required for their VDH concept. The original well design was modified to give a deployment zone diameter of 0.83m with a 0.76m outer diameter casing, using steel for the containers and casing instead of titanium. In addition to well design, this report also gave engineering details of canister design, emplacement technology and retrieval mechanisms. It was concluded that it was possible to drill the borehole with the-then existing technology but that it represented one of the biggest challenges to the drilling industry. It was estimated that it would take around 137 days to drill the hole and it would cost around EUR4.65 ($6.8) million.

The most recent and comprehensive study of the status of drilling technology for DBD was carried out for the NDA in 2008 [17]. It was concluded that in an appropriate geology such as granite, a borehole with a clear, useable diameter of 0.5m, drilled and cased to a depth of 4km, is perfectly practicable using existing technology with some development of tools and systems. Larger holes, diameter up to 0.75m, would be difficult to implement beyond 3km, while 1.0m holes are considered impractical at the present time. Among the other outcomes of this study were that it would take around nine months to drill and case a 4km deep, 0.5m borehole and between 6 months and 2 years to emplace the waste packages, depending on size, number and method used. The first such borehole would require a lead-in time of two years and cost about GBP20 ($32) million, although savings on subsequent holes, especially on the same site, could approach 50%.

The maximum size and depth of practical boreholes restricts the types of wastes for which DBD would be appropriate to those with small to moderate volumes, mainly high-level wastes, including spent fuel. A kilometre of 0.5m borehole can dispose of approximately 200m3 of packaged waste or 690 vitrified HLW containers.

Theoretical studies

A criticality analysis will be important for concepts in which large amounts of potentially fissile material are disposed of, such as LTVDD-2 [see p17], in which spent fuel pins are closely packed in the containers. Taking this as an example, the first stage to consider is when water gains access to the container, and might form thin films between the fuel pins and the enclosing lead. However under these conditions there is no possibility of criticality. At the other extreme is the post-closure situation when the container has failed completely and aqueous fluids have leached out most of the lead matrix around the fuel pins.

Notwithstanding the facts that fluid flow rates at the depths in question are too low for this to happen and that there are no foreseeable hydrogeochemical processes that could bring it about, this would effectively leave the pins surrounded by water. Such a situation would be analogous to the consolidated storage of used fuel pins in metal boxes in ponds – where again there is no question of criticality arising. Nevertheless, a full criticality analysis of the disposal that takes account of predictable changes in the isotopic composition of the spent fuel over long periods must be undertaken.

Then, after this criticality analysis, and following a successful performance assessment [see p18], the next step would require practical tests.

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Demonstration

Demonstration, testing and development of several of the necessary technologies require a full sized (0.5m inner diameter) cased borehole, but one that is shortened to a depth of a few hundred metres. The only other constraints are that it be in granitic host rock and that its bottom end should be readily accessible from pre-existing tunnels or mine workings to enable examination of the outcomes. (Provided the depth and geological conditions are appropriate, other host rocks are possible for DBD, such as salt.) This could be done with a smaller drilling rig than a full-depth borehole and consequently be relatively inexpensive. The drilling programme would probably require around $1-2 million, with subsequent investment stepped up as justified by results.

Following the appointment of a deep drilling consultant, a site would have to be identified and the necessary planning permissions obtained for a borehole and demonstrations in which no radioactive materials would be involved. Since a prerequisite of the site is that it be near deep underground workings, the geology would be well known, eliminating the need for exploratory drilling. The programme would get under way with the issuing of a drilling contract and the sinking of the borehole to a depth slightly beyond that from which it could be accessed from the pre-existing workings.

The hole would then be lined with steel casing. The bottom hundred metres or so of the casing would have some sections perforated with circular holes of various sizes and others with vertical slots for testing and demonstrating the effective emplacement of grouts etc. A full-sized container, with over-pack if required by the concept, filled with simulated waste would then be deployed in the borehole. The same package could be repeatedly emplaced and recovered to test various methods and equipment and demonstrate reliability of package deployment and the ability to recover packages in the unlikely event of a problem.

Possibly the most important series of demonstrations would be those relating to the emplacement of materials to fill and seal the spaces around the waste packages and gaps between the casing and wall rock and to evaluate the effects of radioactive waste upon them. For concepts like LTVDD-1, simulated waste packages containing an electric heater could be emplaced, followed by installation of cementitious grout which should flow into the voids and set under the predicted temperature conditions. The temperature could then be increased through the peak levels predicted by heat flow modelling, and the outcome could be examined by accessing the borehole from underground workings.

For a spent fuel concept like LTVDD-2, a crucial demonstration would be of the successful emplacement, melting and solidifying of the HDSM. The effectiveness of this process, the optimum number of packages to be deployed in a batch and the quality of the seal can again be demonstrated by accessing the borehole from underground. During demonstrations of this sort, the waste package, the casing and the borehole can be instrumented, e.g., with thermocouples, to monitor conditions and evaluate the accuracy of heat flow modelling.

An important demonstration would be the cutting of uncemented casing above the deployment zone, its recovery and the effective sealing of the borehole. Cutting and withdrawing the casing would enable seals to be made directly to the wall rock and recovery of the casing for possible further use would significantly reduce costs. The demonstration of 'conventional' borehole sealing methods at the larger diameters required for DBD should be relatively straightforward but, if rock welding is to be included, it would be necessary to over-pressure the test section of the borehole to simulate the higher pressure and other conditions of an actual disposal borehole.

While expert opinion is that a fully cased borehole with a clear diameter of 0.5m to depths over 4km is achievable with current technology, it has never actually been done. It is therefore necessary to demonstrate that this is possible in an appropriate host rock. The first step would be identification of a site with suitable geology for the borehole and demonstrations with inactive, simulated waste packages. This need not be at the same site as the technology demonstration borehole. Neither need it be a potential DBD site, although choosing one could deliver significant benefits should a subsequent decision to implement disposal be made.

The demonstration borehole should be drilled to the maximum depth possible with the available equipment and could even be used to evaluate different drilling methods and systems.

Having proved the drilling capability, the other main demonstrations would relate to the deployment and recovery of waste packages to and from full depth and the evaluation of different methods (e.g., drill string or coiled tubing), deployment strategies (e.g., batch sizes) and timings. At this stage the possibility of using a lighter rig for full depth deployment, grouting and sealing should also be investigated. Releasing the original rig to drill the next borehole would greatly expedite the disposal programme and further reduce costs.

As with the technology borehole, the full scale hole could be instrumented and, by deploying electrically heated packages, used to validate heat-flow models and other effects at real disposal depths.

Conclusion

A number of DBD concepts for vitrified HLW, spent fuel and fissile materials have passed the scientific proof-of-concept stage. A performance assessment has confirmed the strength of the generic safety case for DBD, although more detailed quantifications of individual concepts still need to be made. Technologies exist for drilling the boreholes, deploying and recovering waste packages, creating the near-field engineered barriers and sealing the boreholes. All that is needed are practical demonstrations that they can be successfully employed at the depths required. The potential returns for the management of high-level wastes are out of all proportion to the relatively modest investment required to start such a programme.

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Deep boreholes exhibit substantial potential for the disposal of spent nuclear fuel and other high-level radioactive waste and warrant additional study in several areas. Criteria for site selection and the characterization of deep boreholes for suitability should be further evaluated. More detailed analyses of operational and engineered systems for waste emplacement are required. Borehole seals are clearly important barriers for waste isolation and their long-term behaviour needs to be more fully assessed. Modelling of coupled thermal-hydrologic-mechanical-chemical behaviour near boreholes with emplaced waste is needed to better understand borehole stability and alterations to the host rock in the disturbed zone. Compounds that sequester radionuclides, particularly radioactive iodine, should be evaluated as additives in the borehole and seals. Performance assessment analyses should be extended to consider a complete list of relevant features, events and processes, to incorporate more detailed process modeling, and to be scaled up from a single borehole to multiple boreholes.

-Bill W. Arnold, Peter N. Swift, Patrick V. Brady, S. Andrew Orrell, and Geoff A. Freeze

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