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Deep borehole disposal (DBD) methods

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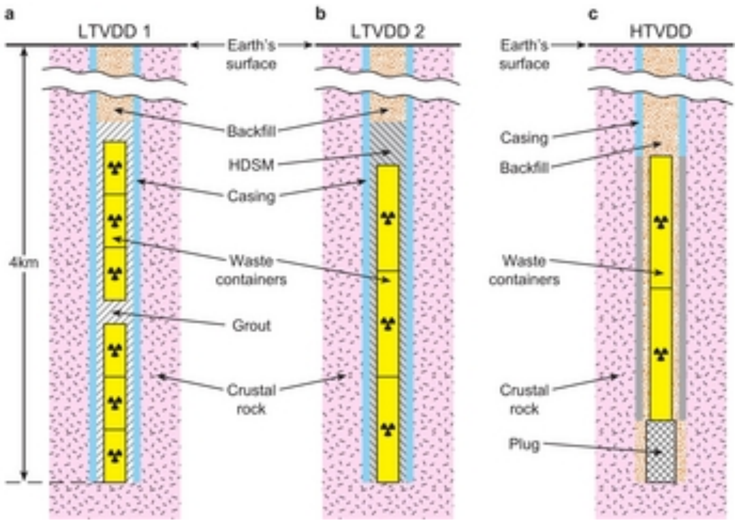
Since DBD, or VDD (very deep disposal) has become a real possibility through the advances in drilling technology, research is being carried out in very few places. Nevertheless, it is regarded as an option in some countries. By Fergus Gibb



Methods of deep borehole waste emplacement compared

VITRIFIED HLW

In LTVDD-1 (low-temperature very deep disposal – version 1) [12], cylindrical stainless steel containers of vitrified reprocessing waste are placed in a stainless steel over-pack with a wall thickness of around 2cm after a period of cooling. The 0.47m in diameter and 1.45m long packages are placed in small batches over the lowermost 1km of a borehole sunk 4km into an appropriate host rock. The cased borehole has an inner diameter (ID) of at least 0.5m. After a few packages are placed, a special, very fluid, high-temperature cement similar to those used in geothermal energy wells is pumped down the hole to fill the space between the packages and the casing and any gaps between the casing and the wall rock (Figure a). After the cement sets, emplacement continues. When emplacement is complete, the hole above the deployment zone is backfilled with crushed host rock and permanently sealed at intervals to prevent fluid flow back up the borehole. Heat flow modelling [12, 13] indicates that temperatures in the borehole adjacent to the waste packages and in the wall rock will peak at 100° to 200°C above an ambient temperature of between 60° and 140°C between 1 and 3 years after emplacement.

SPENT FUEL

The VDH (very deep holes) concept was introduced by SKB in 1989 and featured in its 1992 Project on Alternative Systems Study (PASS). In this concept [14] four intact BWR fuel assemblies are placed inside a 4.8m long titanium cylinder 0.5m in diameter and the voids filled with concrete. These waste packages are deployed over the bottom 2km of a 4km deep, 0.8m diameter borehole fitted with 0.6m diameter titanium casing. The annulus between the packages and casing is filled with a high density deployment mud and the packages separated vertically by a 1m long cylinder of compacted bentonite swelling clay. Above the deployment zone the hole is sealed with bentonite with the top 500m sealed with asphalt topped by a concrete plug. It was concluded that the long-term safety of VDH disposal 'is potentially as good as the long-term safety of a KBS-3 repository' but would be more difficult to demonstrate [see also p20].

In the USA, a 2003 MIT report recommended that DBD for spent fuel had the potential to significantly reduce risk (compared to mined repositories) and merited a significant R&D programme. It has led to a project currently being evaluated by the joint Sandia National Labs and MIT as a possible alternative to Yucca Mountain.

Another approach, LTVDD-2 (low-temperature VDD – version 2), proposes removing spent UO2 or MOX fuel pins from assemblies after a period of post-reactor cooling [7, 12]. Around 1300 pins (equivalent to ~4.5 PWR assemblies) would be placed inside a 4.6m long cylindrical stainless steel container with an outer diameter of 0.45m and a wall thickness of 2.5cm. The container is heated slowly to ~ 335ºC in an inert atmosphere (e.g., N2) to prevent any oxidation of the zircaloy cladding; then molten lead (Pb) is poured in to fill the remaining space. It is then sealed, cooled and stored. Then the containers would be axially deployed over the lowermost 1 to 2km of a 4 to 5km deep, fully-cased borehole with a clear ID of at least 0.5m. A special high-density support matrix (HDSM) is employed to eliminate any possibility of damage from load stresses imposed by the overlying stack. This HDSM is a fine Pb-alloy shot released just above the topmost container. The shot sinks rapidly through the aqueous borehole emplacement fluid to fill the annulus between the containers and casing, and in any gaps between the casing and the wall rock. Within weeks of emplacement, [7] radioactive decay heat from the spent fuel will generate temperatures 100-200ºC above ambient and melt the shot to create a dense liquid that will displace the aqueous fluid upwards and fill any remaining voids between the containers and wall rock. Within a few decades, as the decay heat diminishes, this molten alloy will cool and solidify, effectively soldering the containers into the borehole.

Other DBD concepts for spent fuel include HTVDD (high-temperature VDD) (Figure c) [15] in which the thermal loading of the containers is high enough to cause partial melting of the granitic host rock. With declining heat output, these partial melts cool and crystallize, sealing the containers into a sarcophagus of solid granite. Heat flow modelling and experimental studies [12] confirm the viability of the concept but further R&D is required before HTVDD could be taken into a practical demonstration.

PLUTONIUM

A version of DBD (LTVDD-3) has been proposed specifically for disposal of plutonium and other actinides [16]. The Pu is immobilised by incorporating it into the crystal structure of a material such as zircon, uraninite and zirconolite that is known to be in equilibrium with natural granitic rocks. (Zirconia, PuO_2 or a mix of PuO_2 and UO_2 (MOX) could be equally suitable). Small fragments of the waste form are mixed with crushed granitic host rock, which is then formed into a cylinder and partially melted before recrystallizing into solid granite.

The borehole, which need be no wider than 0.27m, is sunk into the granitic basement to a depth of 5 or 6km and fully cased. The Pu-containing granite cylinders are emplaced over the lowermost 2 or 3km of the hole. Finally the borehole is backfilled with crushed host rock and sealed. In this concept the Pu is in thermodynamic equilibrium with its host phase which, in turn, is in equilibrium with the enclosing granite cylinder. The intra-rock fluids which will eventually seep from the host rock into the borehole will have equilibrated with the host rock over many millions of years and hence will also be in equilibrium with the granite cylinders. This multiple equilibrium should ensure that no Pu leaches out into the borehole fluids and so remains safely contained indefinitely. This is essentially the same principle that has kept the actinides in natural uranium deposits contained for hundreds of millions of years.

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