A New Approach For Direct Disposal Of Spent Fuel Into Deep Vertical Boreholes In A Salt Repository - 8232

W. Bollingerfehr, W. Filbert, J. Wehrmann
DBE TECHNOLOGY GmbH
Eschenstrasse 55, D - 31224 Peine, Germany

ABSTRACT

This paper describes the reference concept for the disposal of heat generating radioactive waste in Germany. It also highlights a new approach to reduce efforts for the transport and handling of waste canisters by introducing a new canister type for spent fuel (BSK 3). The objectives and the scope of a corresponding research and development program performed in the context of the 6th European Framework Program will be presented. The entire emplacement process and the technical components will be described and illustrated. The program for the corresponding 1:1-scale demonstration tests and the location of the test site will be explained. Eventually, an outlook on the planned demonstration test will be given.

INTRODUCTION

Rock salt was selected in the early 1960s as the preferred host rock for a repository for heat generating wastes in Germany due to the unique geohydrologic, thermal, and geomechanical properties as a self-healing impermeable rock. In Northern Germany, a large number of salt domes with huge dimensions, many of them principally suitable to host a repository, exist. In 1977, at the end of a time consuming selection process, the salt dome in Gorleben was selected out of a group of preselected salt domes for further exploration. Until October 2000, when the Federal Government and the nuclear industry agreed to stop further underground exploration at the Gorleben site for at least 3 and max. 10 years, almost all necessary data to describe the suitability of a repository site were collected. Exploration from surface was accomplished, 2 shafts constructed and the first square of the underground exploration mine excavated accompanied by geotechnical and geophysical monitoring.

The German reference concept for the disposal of heat-generating radioactive waste comprises the emplacement of canisters containing vitrified waste in deep vertical boreholes, whereas spent fuel will be disposed of in self-shielding POLLUX® casks in horizontal drifts inside a salt mine [1]. In the disposal concept, unshielded canisters with vitrified high-level radioactive waste (HLW) are to be emplaced in up to 300 m deep boreholes with a diameter of 60 cm. The disposal zones for both, spent fuel and vitrified waste, are to be constructed in a salt dome at a depth of 840 m. In order to facilitate the fast encapsulation of the waste by the host rock (rock salt), the boreholes are not to be furnished with lining. The POLLUX® casks, the 65-tonne heavy carbon steel casks, will be laid down on the floor of a horizontal drift. The space between the casks and the drift walls will be backfilled with crushed salt.

According to German legislation, obtaining a license to construct a repository requires previous demonstration to the competent authority that the level of protection (dose or risk) can be met to a high level of confidence. In the case of waste canister transport and handling systems, the fulfillment of the regulatory requirements can be provided by means of 1:1-scale demonstration and reliability tests. The transport, handling and emplacement techniques of the POLLUX® cask were subject to successful demonstration and in-situ tests performed in the 1990s. As a result, the atomic law was amended accordingly in 1994.

NEW APPROACH FOR DIRECT DISPOSAL OF SPENT FUEL

In order to harmonize and optimize the emplacement technology for both categories of waste (vitrified waste and spent fuel), alternative technical approaches were sought during the past couple of years. In this context, the borehole emplacement technique for consolidated spent fuel as already foreseen for high-level reprocessing waste was reconsidered. A starting point was the decision of the German nuclear industry to develop a new fuel rod canister (called BSK 3 canister), which can be filled with the fuel rods of 3 PWR or 9 BWR fuel assemblies. The BSK 3 canister was designed to contain a total activity of up to 0.8E+17 Bq, and to be capable of transferring a maximum heat load of 6 kW. For interim storage purposes, the minimum decay time of the spent-fuel assemblies must be determined so that the maximum allowable gamma and neutron dose rates at the surface of the interim storage cask as well as the permissible structural and fuel-rod cladding temperatures will not be exceeded. These design criteria as well as further requirements imposed by atomic and mining laws are compiled in Table I.

Table I. Design criteria for BSK 3 canisters

Design criteria	Explanation	
Inventory of heavy metals	Loading with fuel rods from disassembled fuel assemblies from pressurized and boiling water reactors	Up to 1.63 tHM
Heat	Max. heat output capacity of the canister contents	6 kW
	Max. cladding strain for the storage time by limitation of the cladding temperature	< 1 %
	Max. tangential tension	< 100 MPa
Criticality	Neutron multiplication factor during transport and inspection conditions	$k_{eff} + 2\ \sigma < 0.95$
Tightness	Allowable He-Standard-Leakage rate, sealing of the primary lid	$1 \cdot 10^{-3}$ hPa *l/s
	Allowable He-Standard-Leakage rate after welding of the secondary lid	<< $1 \cdot 10^{-7}$ hPa *l/s
Strength	Design for maximum isostatic rock pressure in the repository	30 MPa

Based on the political decision to phase out of nuclear energy, the anticipated amount of radioactive waste has been assessed (see Table II). Heat generating vitrified HLW is contained in standard Cogema canisters, low heat-producing high-active technical waste, mainly caps and claddings, in CSD-C canisters. For direct disposal, spent fuel is packed in so-called BSK 3 canisters. The main characteristics, including the numbers that need to be disposed of, are given in Table II as well.

On average, an HLW canister contains 412 kg of high-level waste from the reprocessing of nuclear fuel vitrified in glass. A CSD-C canister contains claddings and structural parts as well as technical waste from reprocessing in compressed form. A BSK 3 canister contains the fuel rods of 3 PWR or 9 BWR fuel assemblies. These three different types of canisters with nearly the same diameter are shown in Fig. 1.

The new BSK 3 concept offers the following optimization potentials:

- The new steel canister is nearly of the same diameter as the standardized HLW canisters for HLW and compacted technological waste from reprocessing abroad.
- The standardized canister diameter provides the possibility to apply a common transfer and handling technology for both categories of waste (vitrified HLW and spent fuel) and thus to save money.
- The new BSK 3 canister is tightly closed by welding and designed to withstand the lithostatic pressure at the emplacement level.

- The residual heat generation of a canister loaded with fuel rods burned up to 50 GWd/tHM will enable its emplacement in a salt repository after only about 3 to 7 years after reactor unloading of the fuel assemblies. This has been verified by thermal calculations.
- Compared to the emplacement of POLLUX® casks the creep process of the host rock (rock salt) will be accelerated and lead to a faster (earlier) entire encapsulation of the waste canister. This might reduce the requirements for geotechnical barriers.

Table II. Characteristics of the Waste Canisters for Disposal of Heat Generating Waste

		HLW Canister	CSD-C Canister	BSK Canister
Number of canisters		4.778	8.764	ca. 5.525
Number of boreholes needed		30	55	95
Length	mm	1.338	≤ 1.345	4.,980
Diameter	mm	430	≤ 440	≤ 440
Total mass	kg	ca. 492	≤ 850	5.226
Mass HM	tHM	-	-	1.6
Heat generation • at loading • after 10 years • after 30 years	kW	 1.120*) 0.67**)	 0.02	 21.220 3.030 1.930

*) after 9 years **) after 29 years

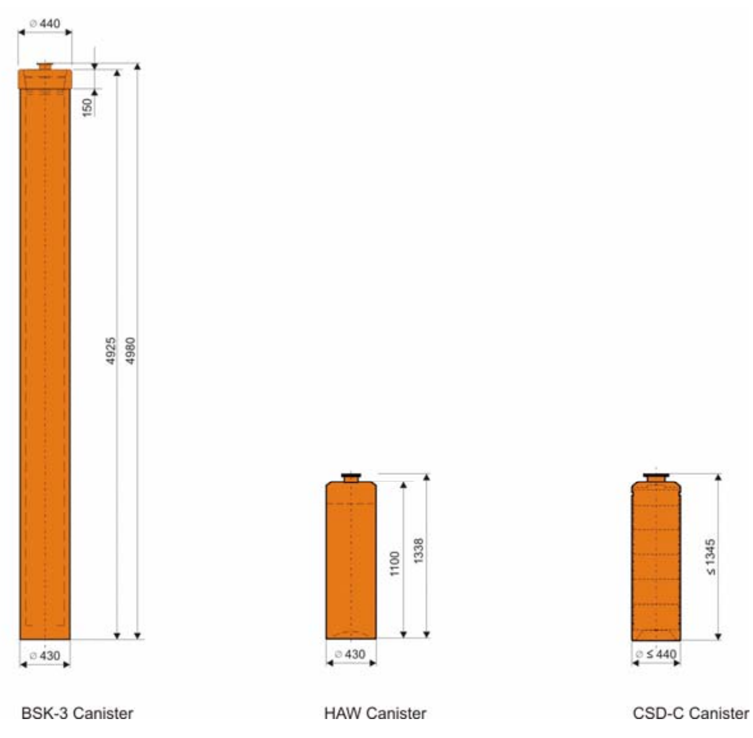

Fig. 1. BSK 3 canister, HLW canister, and CSD-C canister

The BSK 3 concept, therefore, may provide a common solution for the emplacement of all types of heat generating radioactive waste in Germany and a considerable reduction of the necessary effort in terms of time and costs. As a consequence, a research program was launched in order to develop and test the necessary technical components for the transport and handling of BSK 3 canisters.

OBJECTIVES AND CONTEXT OF A R&D PROJECT FOR THE DEVELOPMENT OF THE BSK 3 EMPLACEMENT TECHNOLOGY

In cooperation with the German nuclear industry, DBE TECHNOLOGY GmbH decided to set up an appropriate R&D program. The main objective was to develop the necessary components for demonstrating the functionality and reliability of a suitable emplacement technology. In addition, the results of the tests and investigations should provide all information required for licensing this new backend technology, satisfying the legal requirements for a German HLW repository.

In the context of a call for proposal for integrated projects in the area of waste management in 2003 - launched by the European Commission - the BSK 3 concept was recommend to a consortium of European Waste Management Organizations (WMOs) and accepted eventually as a part of the five-year integrated project ESDRED (Engineering Studies and Demonstration of Repository Designs). The integrated project (IP) ESDRED includes four technical tasks (called modules) dealing with the construction and behavior of engineered buffer material, the transport and emplacement systems for different types of waste canisters, the transport of heavy loads (up to 50 tons) and the construction and testing of a low ph-sealing [2].

Thirteen partner organization from nine European countries are developing new technologies and processes related to their specific national repository concept. As far as possible and technically reasonable, common solutions will be developed. In this context, the BSK 3 canister transport and emplacement concept is specific to the German reference concept in salt but it might be applicable to other host rocks as well.

In order to optimize the emplacement process for spent fuel elements by introducing the BSK 3 canister, the following objectives for this research and development project were set up:

- General objective:
  - to develop and test the emplacement technology for BSK 3 canisters on a 1:1-scale

- Detailed objectives:
  - to prove the technical feasibility of constructing the entire emplacement system for BSK 3 canisters and the single components
  - to prove the operational safety by adequate demonstration tests
  - to derive safety measures for the operation in a repository
  - to investigate the approvability of the emplacement system

The IP ESDRED, coordinated by the French WMO ANDRA, started on February 1, 2004 and will last until the end of January 2009. The main financial resources are made available by the national WMOs. The European Commission is supporting the project with approx. 35 % of the total costs.

The development and demonstration of the German BSK 3 emplacement technology - as part of the IP ESDRED - will be financed by the European Commission, the German project agency (PTKA) and the German nuclear industry. The latter one in particular provides money for manufacturing the components of the emplacement system.

BSK 3 EMPLACEMENT SYSTEM

According to the new approach, BSK 3 canisters as well as HLW canisters with vitrified waste will be disposed in vertical boreholes with a depth of about 300 m and a width of about 60 cm. The tolerable max. temperature of 200°C at the contact between waste canister and host rock (rock salt) leads to borehole-separation distances of approximately 50 m.

The emplacement system developed for the handling and disposal of BSK 3 canisters comprises a transfer cask, which provides appropriate shielding during the transport and emplacement process, a transport unit consisting of a mining locomotive and a transport cart, and an emplacement device. Fig. 2 shows the components of the entire transport and emplacement system selected out of a variety of options for the transport and emplacement of BSK 3 canisters in an underground emplacement drift. Aboveground, the BSK 3 canister is inserted into the transfer cask, which is transported by the transport cart through the shaft to the emplacement drift underground. The mining locomotive drives the transport cart with the transfer cask to the emplacement device. The emplacement device, previously positioned on top of the emplacement borehole, lifts the transfer cask from the transport cart, tilts the cask into an upright position and lowers it down onto the top of the borehole lock. Borehole lock and the lock of the transfer cask will be opened simultaneously and the BSK 3 canister will be lowered down by means of a canister grapple.

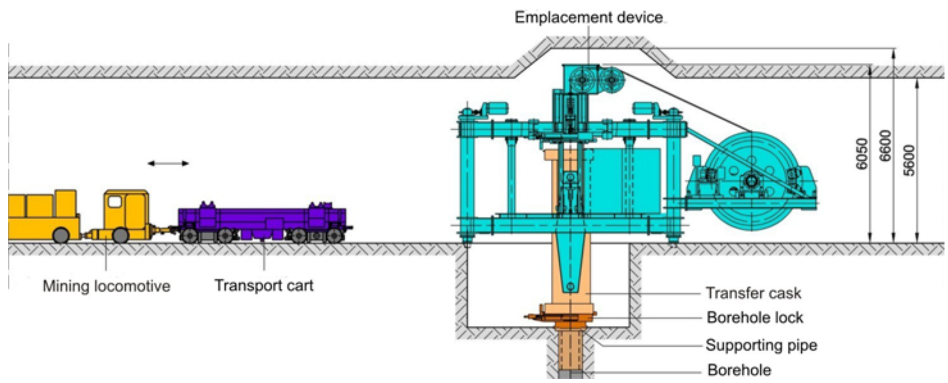

Fig. 2: BSK 3 transport and emplacement system

MAIN COMPONENTS TO BE DEVELOPED

The selected BSK 3 emplacement system requires the development of the following new components:

- a BSK 3 canister, capable to contain rods of 3 PWR or 9 BWR fuel assemblies
- a transfer cask for safe enclosure and transport of the BSK 3 canister
- an appropriate emplacement device
- a borehole lock and
- a transport unit consisting of a transport cart and a battery driven mine-locomotive for rail bound transport in the repository

An original idea to reuse the transport cart, successfully applied during the demonstration tests with POLLUX® casks in the 1990s, had to be discarded. From an economical point of view it was less expensive to build a new one then to modify the existing one. However, the battery driven mine-locomotive will be used again.

Transfer cask

Transfer casks will be used in the repository to enable a safe transport of the BSK 3 canisters from the hot cell of the repository surface waste reception station to the final destination in a borehole at the emplacement level.

The body of the transport cask consists of a thick-walled hollow cylinder made of cast iron with nodular graphite (GJS). The wall thickness and wall structure of the cask body are designed in accordance with the requirements concerning mechanical strength and gamma and neutron shielding.

There are two drill hole lines in the cask wall on separate circles which are filled with polyethylene rods which serve as neutron moderators. The neutron shielding at the base and lid is effected by flattened disc-like neutron moderators. Direct radiation transitions are avoided by means of constructional measures. The locks are made of stainless steel and are screwed to the cask body. The flat slide latches integrated into the locks work like drawers and run in slide bars. When in locked position the flat slide latch is kept in place by two locking bolts set into the side walls.

The transfer cask does not have any inherent mechanism to open and operate the flat slide latches. Cask opening and closing is effected at the base by means of the borehole lock mechanism and at the lid by means of the emplacement device (shielding cover). During the lowering processes opening bolts in the borehole lock and shielding cover mechanism slide into recesses in the latches and open them. At the cask base the opening bolts of the borehole lock are part of the borehole latch. The opening of the borehole causes the simultaneous opening of the transfer cask.

There are two diametrically positioned trunnions at the ends of the cask body to facilitate the handling of the transfer cask. The trunnions have an additional offset collar next to the collar which during transport serves to fasten a lifting sling when in the surface transfer area and to allow it to be picked up by the emplacement facility.

BSK 3 dummy canister

For the demonstration and test purpose a BSK 3 dummy canister will be used which fulfills all geometrical and weight requirements but does not contain radioactive material. The BSK 3 dummy canister will be provided by the German nuclear industry in due time for the test campaign.

Emplacement Device

The emplacement device (Fig. 3) is the central device of the entire BSK 3 canister emplacement process. Accordingly, it is equipped with all means for the safe handling of the transfer cask and BSK 3 canister. In a final repository an emplacement cycle usually includes the following procedures: The BSK 3 canister will be delivered in the transfer cask on the transport cart to the emplacement drift at the determined position on top of an emplacement borehole. The transfer cask will be lifted off the transport cart by the emplacement device and swiveled into an upright position after the transport cart has been removed. After lowering the transfer cask onto the borehole lock and opening the transfer cask and borehole lock, the BSK 3 canister - fixed with the canister grapple of the lifting gear - will be lowered to the planned position in the borehole. The canister grapple will be removed and the transfer cask and the borehole lock closed. After swiveling the transfer cask into a horizontal position, the transport cart will be again driven under the emplacement device and the transfer cask is placed on the wagon. Finally, the transport cart and transfer cask will be driven out of the emplacement drift for reloading. Accordingly, the emplacement device basically consists of the following assembly units:

- Lifting gantry
- Flap-frame with controls
- Swivel gear
- Canister lifting gear including hoist cable and lifting tackle
- Shielding cover

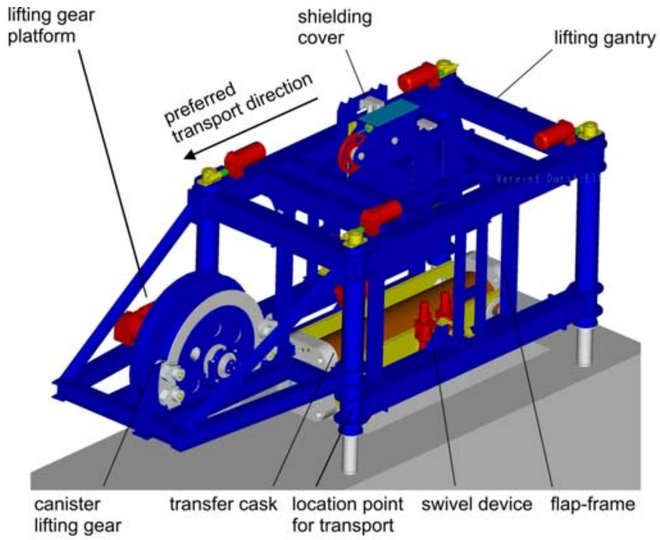

Fig. 3: Emplacement device

Borehole Lock

On top of the borehole a borehole lock is connected tightly with the supporting pipe, which stabilizes the upper 4 m of the borehole. The borehole lock (Fig. 4) provides the sealing of the borehole and consists of a body and a flat slide latch as well as the equipment for the slide latch guidance and the slide motor. The upper part of the body is collar-shaped to take the transfer cask. Four guide pins at the base of the collar help line up the transfer cask. The flat slide latch is a massive block-shaped steel body which is moved by a spindle and a geared engine unit. The flat slide latch has two opening bolts to unlock the borehole lock and to mechanically connect it to the transfer cask's locking latch.

The lower part of the body is flange-shaped to allow its connection to the borehole support pipe. In the upper, inner part of this offset flange ducts carry used air and dust from the borehole via a ring channel to the connection with the mining ventilation system.

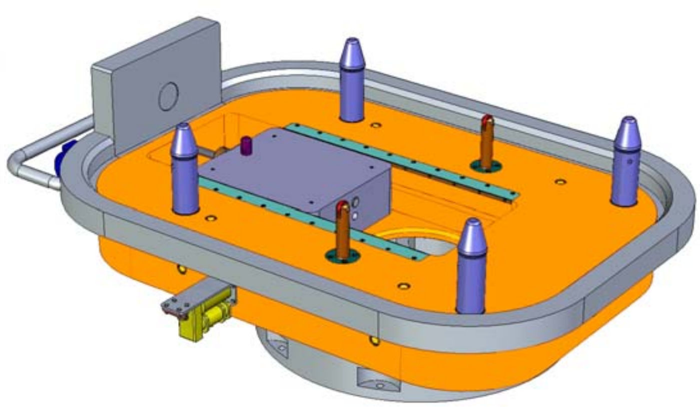

Fig. 4: Borehole lock

Once a borehole is completely filled with BSK 3 canisters and backfill a quality assured borehole sealing will be in installed. Prior to this activity the borehole lock will be dismantled.

Transport Cart

The transport cart (see Fig. 2) is used for repository internal rail bound transportation of the transfer cask from the surface via the shaft to the emplacement location. The cart has four axles and a pick-up attachment under the middle of the chassis for transportation by stationary lifting gear and a coupling at each end for traction units.

During transportation with the transport cart the inner collar of the transfer cask trunnions serves as a bearing. The design of the frame parts of these bearings takes the required operating space for the loading (swivel girder) of the emplacement device into consideration. To lift the transfer cask free from the transport cart half-covers, a lifting distance of 200 mm is necessary. This distance makes allowance for a 30-mm protrusion of the half cover hinges above the middle of the carrying-pegs and a max. spring relaxation of the transport cart of 20 mm.

For the envisaged demonstration tests the existing battery-powered locomotive will be used. In the final repository the locomotive gauge will have to be widened.

DEMONSTRATION PROGRAM

Due to the lack of an underground laboratory in salt in Germany the intention is to perform the demonstration tests in a first step in a surface facility. For this purpose a former turbine hall of a power station in the village of Landesbergen in the vicinity of Hanover, Lower-Saxony, has been rented. This building provides the possibility to simulate the emplacement process of a BSK 3 canister in a vertical borehole. The components of the emplacement system will be assembled at a level of 10 m above ground floor. Thus, a 10-m long vertical steel metal casing will simulate the emplacement borehole. The BSK 3 canister will be lowered down by the grapple of the emplacement device and - different to a real repository - removed again for further tests afterwards.

The test program comprises

- Demonstration tests
- Simulation tests
- Tests to resolve operational disturbances

In total approx. 500 complete emplacement cycles will be simulated in order to obtain information on the reliability of the entire system and of each component.

STATUS OF PROJECT AND OUTLOOK

All the components have been designed in detail, the drawings and reports evaluated by external experts. The components will be manufactured until spring 2008. The construction work to prepare an appropriate test facility will be performed from February to March 2008. The delivery of the individual components will start at the beginning of 2008 and accomplished with the delivery of the transfer cask in May 2008. After the individual components have been accepted on site the demonstration program - performed in two shifts - will commence in May and last until November 2008.

The intention is to show the reliability of the emplacement system by means of a large number of demonstration tests and to draw conclusions and give recommendations for industrial application in the repository.

In late autumn of 2008 an international workshop on emplacement technology for an HLW repository is planned to be held at the DBE TECHNOLOGY GmbH headquarters in Peine. The workshop will be combined with a visit to the test facility to give participants the opportunity to witness with their own eyes the quality of this unique emplacement system.

REFERENCES

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