Status of Equipment Development for a High-Level Waste Repository in Germany - 9552

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ABSTRACT

In Germany, a potential site for a deep geological repository mainly for heat generating high-level waste was selected back on February 22, 1977: a salt dome located near the village of Gorleben, at the shores of the Elbe River in Northern Germany. Concurrent with site exploration from the surface, and later exploration mine construction, a large-scale R&D effort was conducted to have the science and technology needed to license and later operate a repository available when needed. An important part of these efforts was the development and 1:1 scale demonstration of all technologies required to run a repository, which had not been state-of-the-art. Underground exploration of the Gorleben site has come to a moratorium due to political decisions taken by the former Federal Government formed by a coalition between the Social Democrats and the Green Party back in 2000. However, research and development in regard to emplacement techniques and equipment has continued. This paper reflects the consistent, long-term technological effort that has led to having available all advanced technologies required to run a repository for spent fuel and HLW. The paper details previous achievements and points at present optimization work.

INTRODUCTION

In Germany, research and experimental work on radioactive LLW disposal began as early as April 1967 in the former Asse salt mine with a mining history of about 70 years. Research and experimental work on remotely handled ILW disposal started in the summer of 1972 (Fig 1). Until discontinuing waste disposal at the end of 1978 a lot of experience was gained with the technology for safe underground handling and disposal of waste packages. Using the Asse mine as Underground Research Laboratory (URL) research work continued until the end of the 20th century. During this time extremely valuable data were gathered in regard to the handling and disposal of high level waste from heater experiments and other inactive tests. The Asse is now being decommissioned. Based on the experience from operation of the mine and the preparation of its decommissioning, it has become clear that an intensively mined geological formation provides unfavorable conditions for hosting a repository for radioactive waste in regard to its stability and later closure. In general, a long and intensive mining history would therefore be considered a negative aspect in regard to the suitability of a site.

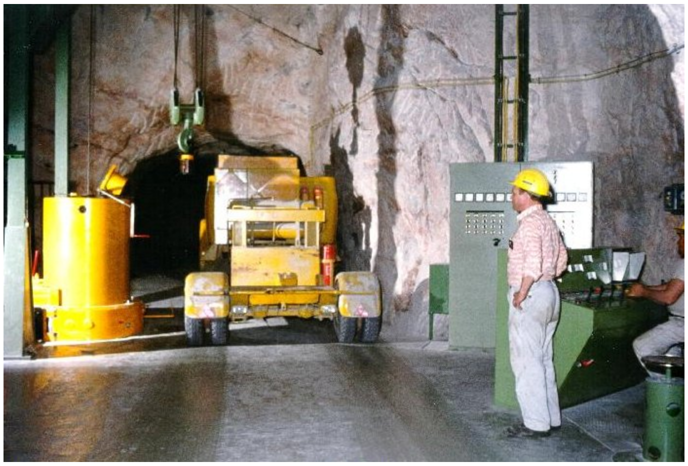


Fig. 1. ILW Disposal at the Asse Experimental Repository

Following the selection of the Gorleben site in 1977, from 1979 on, a comprehensive surface survey program was carried out to characterize the salt dome and the surrounding area, that had never been impaired by mining activities. It was complemented with the construction, after 1986, of a large-scale underground site exploration mine by DBE (German acronym for "German Company for the Construction and Operation of Waste Repositories") for the Federal Government (Fig. 2).

Fig. 2. Gorleben site

In view of the very promising surface exploration results, which strongly suggested the suitability of the site to host a repository, the exploration mine was designed and constructed by DBE in such a way that all important elements, e.g., the access shafts and the surface and underground infrastructure, could later be used as part of the repository without major alterations and refurbishment. After receiving the license, transformation of the site exploration facility into a repository mine can thus be rapidly carried out, and the overall use of economic resources can be optimized.

In spite of the technical achievements, and of the strong and continuing support of the local community, the Gorleben repository project has been in a moratorium since October 2000, pursuant to a political decision of the coalition then ruling Germany. The moratorium implies that only such work is carried out that is necessary to maintain the facility in safe condition and to protect the already incurred investment. The new Federal Government installed in 2005 did not revise this decision, in spite of the fact that the politically motivated issues adduced for introducing the moratorium had all been resolved before the end of 2005.

In spite of the standstill in regard to the Gorleben exploration mine, site independent R&D work for optimization of waste emplacement technology and equipment has been ongoing. An important part of this R&D work has been dedicated to the optimization of the German reference concept for disposal of spent fuel.

INITIAL CONCEPT AND TECHNOLOGY DEVELOPMENT

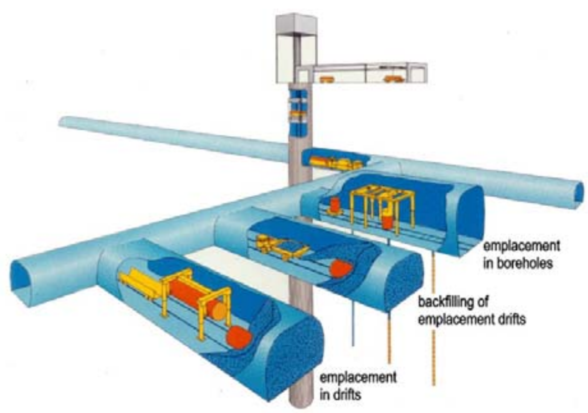
Reference Disposal Concept

In addition to repository site development at Gorleben, a comprehensive equipment development and demonstration program for spent fuel and vitrified waste disposal started in the early 1990’s. Demonstrating the feasibility and safety of spent fuel conditioning, transport to underground, and disposal in a repository mine under simulated conditions in 1:1 scale was the goal of a national R&D effort initiated by the Federal Government.

The work started with the development of a reference concept for the disposal of spent fuel and vitrified HLW in a repository in a salt formation [1] (Fig. 3).

This reference concept, that had been selected from a number of alternatives, anticipates the emplacement of heavy (65 t) self-shielding casks (Fig. 4) containing the fuel rods of up to ten disassembled spent fuel elements (~5 tHM). The casks were designed, manufactured, and tested by GNS (German acronym for “Company for Nuclear Service”), DBE’s main shareholder. The casks were to be disposed of in horizontal drifts of a repository mine at a depth of about 850 m. The void gallery space around the casks was to be backfilled shortly after disposal with crushed salt. Vitrified HLW, in turn, was to be disposed of in up to 300-m deep unlined vertical boreholes with 0.6-m diameter, drilled from the repository galleries at the mentioned depth.

Obtaining a license to construct a repository in Germany requires previous demonstration to the competent authorities that the required level of protection (dose or risk) can be met to a high level of confidence during repository operation and after repository decommissioning and closure. Moreover, it is required that the technological ways and means selected to build and operate the repository are state-of-the-art technology, so that by pointing to existing installations, it can be shown that the proposed system and equipment are feasible. In the early 1990’s neither the required waste encapsulation nor the transport of the resulting heavy payloads in a shaft had ever been demonstrated before. Therefore, a large-scale demonstration plan had to be conducted.



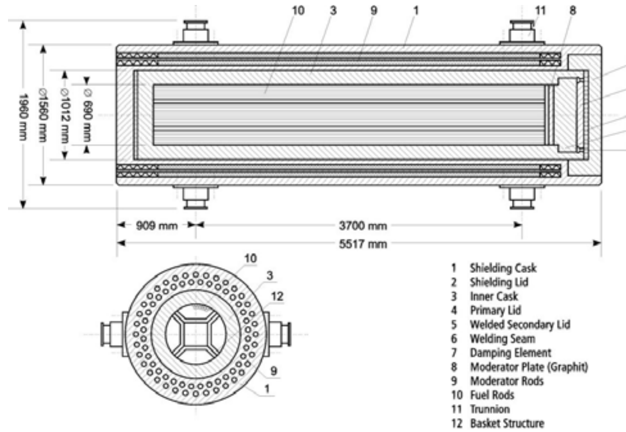


Fig. 3. German Reference Concept for spent fuel and HLW disposal

Fig. 4. POLLUX® cask

Spent Fuel Conditioning for Disposal

For demonstrating the waste conditioning process such a plant was designed and built at Gorleben, the PKA, a German acronym for Pilot Conditioning Plant (Fig 5).

Fig. 5. Pilot Conditioning Plant at Gorleben (source GNS)

The PKA was built and is operated by GNS. Conditioning is the process in which spent fuel assemblies are discharged from dual-purpose, transportation and storage CASTOR® casks into an unloading hot cell. The assemblies are then transferred into the disassembling cell, in which the head pieces are unscrewed (BWR fuel) or cut free from the assembly (PWR fuel), the fuel rods pulled out of the assembly and discharged into a trough, which is later loaded into the final disposal POLLUX® cask in a third hot cell, the loading cell. The cask is subsequently welded tight in a dedicated installation. The fuel assembly structural parts are super-compacted in the disassembling cell and later disposed of as ILW. Fig 6 shows the PKA's cask reception and shipping handling area.

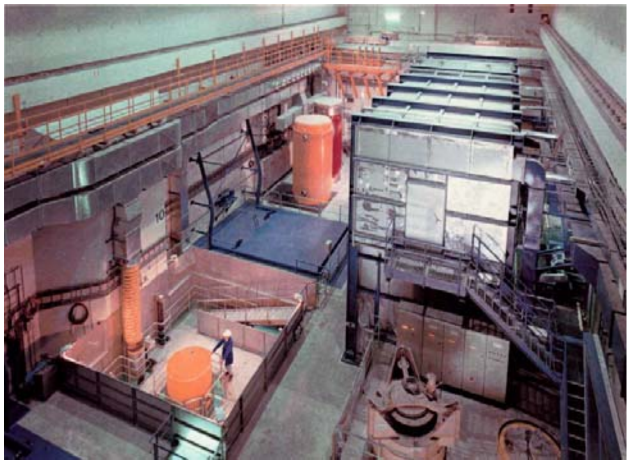
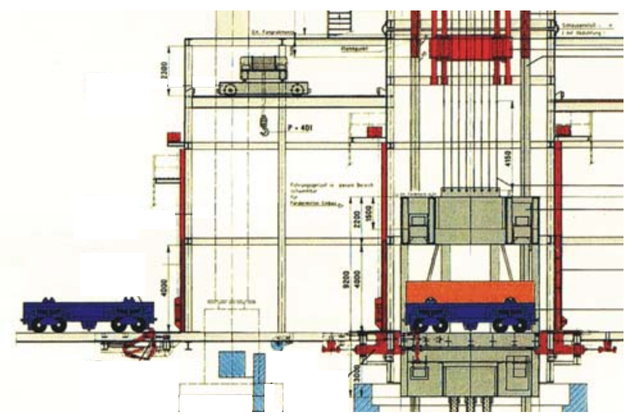


Fig. 6. Cask handling area of the PKA (source GNS)

The PKA was licensed for an pilot operation of 35 tHM. The plant is currently in stand-by operation to be used in case that possibly damaged transportation and storage CASTOR® casks might require repair work. The execution of actual spent fuel conditioning for research purposes depends on further decisions on the Gorleben repository project and on the availability of acceptance criteria for disposal.

Spent Fuel Hoisting to Underground

A comprehensive, worldwide review of heavy-duty hoisting facilities operating in mines unveiled a technological limit of around 40 tons payload, with the loads being conveyed from underground to the surface. In contrast to this, the German reference concept required hoisting about 85 tons payload (cask and conveyance) from the surface to underground. Correspondingly, the feasibility of hoisting such payloads to underground with the level of safety required in the nuclear industry was highly questionable .



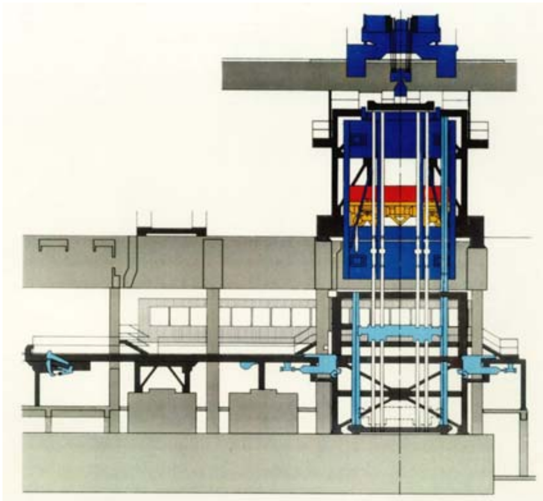


Fig. 7. Shaft surface station for 85 tons payload **Fig. 8. Spent fuel hoisting test facility SST**

A back-up concept was therefore also comprehensively studied which anticipated chopping spent fuel rods into short segments that could be packed into a cylindrical canister with the same external dimensions as the vitrified HLW, i.e. about 43 cm in diameter and 1.3 m in length. The PKA was designed to carry out this operation as well, but this concept was later abandoned as soon as the feasibility of safely hoisting the POLLUX® to underground had been demonstrated.

This was accomplished with a detailed design by DBE of a hoisting facility fulfilling the required payload and mining and nuclear safety specifications. Based on this design, all systems and components were identified that were not state-of-the-art at the time. Specific demonstration work was planned and carried out for all of them, mostly in a dedicated demonstration facility integrating all systems important to safety. Fig 7 shows an outline of the shaft surface station; an outline of the demonstration facility is shown in Fig 8.

Demonstration went on at the SST (Simulation of Shaft Transportation) for about 1000 cycles of loading and unloading the shaft-hoisting cage in order to obtain reliability data on the performance of safety-relevant equipment, which is needed for a risk-informed safety analysis and for the license application. Especially important was testing the systems designed to protect from malfunction of the hoisting engine steering system at the ends of the vertical shaft cage movement. For the case that the engine steering system or the hoisting engine brakes fail to stop the cage as designed, a protection system must prevent the cage from damaging the shaft station structures and endangering the integrity of the hoisting ropes. Such an overwinding incident could lead to a catastrophic course of events, and must therefore be safely ruled out. Fig 9 shows the SST test facility.

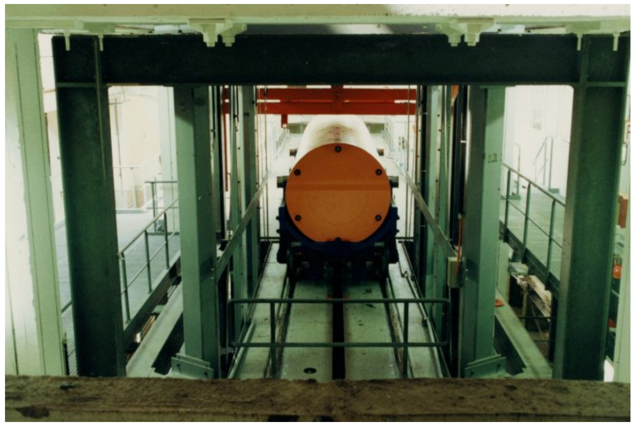


Fig. 9. Test facility SST

In the SST test facility both, a novel overwinding prevention system proposed by DBE for this purpose and a traditional system required by the mining supervisory authority were tested. The SELDA arrestor proposed by DBE performed excellently in repeated tests, so that now an adequate overwinding prevention system for the required payload range is available and is planned to be used in all future German repositories. The second system, consisting of tapered wooden shaft cage guides, is the one traditionally used worldwide in the mining industry, although for much lower payloads. The reserves of DBE in extrapolating the design of such a system for 85 tons payload were confirmed by the last test, carried out at the design cage traveling speed of 5 m per second. The system was completely unable to arrest the cage as intended, resulting in serious damage to the test facility. The total failure of this traditional system usually required by the mining authorities stressed the outstanding importance of equipment demonstration projects for final disposal purposes.

A probabilistic safety analysis of the shaft hoisting system, carried out after finishing the tests, showed the clear superiority of shaft transportation for the safe conveyance of spent fuel to underground compared to access to underground via a ramp. The estimated probabilities of occurrence of catastrophic courses of events were of the order of 10^{-9} per year. With these values such incidents are clearly in the range of rest-risks and they do not need to be considered in the design. This probabilistic safety analysis was worldwide the first of its kind for repository equipment important to safety, and it was based on reliability data derived from 1:1 scale tests.

Underground Transportation and Disposal

Upon reaching the underground shaft landing station the waste packages are unloaded from the shaft cage, conveyed into the disposal drift, and disposed of there, the last operation is the backfilling of void space around the cask.

For the underground transport and disposal, it is important to minimize the height of the equipment, i.e. the loaded transport cart and the disposal machine, as they determine the drift height and thus have a strong impact on rock excavation needs. Moreover, a compact repository layout that minimizes host rock volume needs would require the smallest possible curve radii. For transportation safety reasons, track bound transport was selected, and it was intended to make use of standard systems and components of the railways industry whenever possible. Safety and maintenance needs' optimization excluded the use of external power electricity, and a modular, battery driven locomotive was designed. The 65 tons weight of the POLLUX® disposal cask required a transport cart running on 8 wheels. Furthermore, a compact repository design could be achieved by a skewed layout with 60-degree curves having a radius of 20 m. The last requirement was fairly stringent, as the minimum radius of German railways is 200 m, especially in combination with the height limitation. DBE, in close cooperation with equipment manufacturers, designed and procured for these tasks the system shown in outline in Fig. 10.

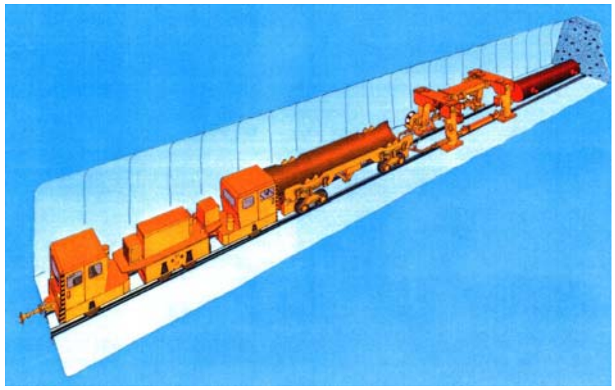


Fig 10: Underground transportation and disposal system

The transport, handling and emplacement equipment of the POLLUX® cask reference concept were subject to successful demonstration in a dedicated surface facility, a view of which is shown in Fig 11.

Fig 11. Waste transportation and disposal tests

Transportation and disposal tests were repeated 1000 times to gather data on the reliability of the equipment. For the waste emplacement machine a single steering equipment failure was registered during the tests, with the machine automatically going into safe stand-by condition, as designed. The transportation cart, which has gimbal-mounted bogies, had difficulties in negotiating narrow curves under full load, showing a certain tendency to derail. Simple design changes were not completely successful as the selected geometry of the axles suspension induced too high restoring forces under full load, making in-deep redesign at a later stage necessary.

In general, DBE's first series of demonstration tests was very successful, and led to an amendment of the Atomic Energy Act in 1994, accepting direct spent fuel disposal as a viable alternative to reprocessing and HLW disposal. And this in spite of the fact that the conditioning plant PKA only became available about 10 years later.

DEVELOPMENT OF ALTERNATIVE CONCEPTS

Waste Canister System

In order to harmonize and optimize the emplacement technology for both vitrified HLW and spent fuel, alternative technical approaches were explored during the past few years. Among others, borehole emplacement, the reference technique for HLW, was also considered for consolidated spent fuel. This was prompted by the decision of the German industry (GNS) to develop a new disposal canister (the BSK 3 canister), which can accept the fuel rods of 3 PWR or 9 BWR fuel assemblies [2]. The BSK 3 concept, jointly developed by GNS and DBE, represents a reversal of the original preference of self-shielding casks, with the corresponding reduction of efforts in regard to the required cask systems on the one hand, and a more complex repository operation technology on the other hand, but without compromising long-term safety features. Notwithstanding, it appeared worthwhile to carry out a new series of demonstration tests in order to confirm, or refute, the advantages and disadvantages the paper studies had unveiled.

Important advantages of the BSK 3 concept include the fact that the canister has the same external diameter as the vitrified HLW canister, so that standardized equipment can be used allowing hoisting to underground, transporting, and disposing of both types of waste with essentially the same equipment. Furthermore, the lower HM content allows for earlier disposal and the very limited void space around the canister in the disposal borehole will be tightly closed by salt convergence in a few months, thus perfectly enclosing the waste in this impermeable host rock. This containment effect is an important safety feature of a salt repository, and it would take several decades to achieve the same conditions in the case of drift disposal with the POLLUX® cask concept. Some important data of the HLW canister and the BSK 3 canister are summarized in Table I.

Table I. Main Data of HLW and the BSK 3 Canisters

		HLW Canister	BSK 3 Canister
Number of canisters		4.778	About 5.525
Number of boreholes needed		30	95
Length	mm	1.338	4.980
Diameter	mm	430	≤ 440
Total mass	kg	About 492	5.226
Mass HM	tHM	-	1.6
Decay Heat	kW		
• at loading			21.220
• after 10 a		1.120[a]	3.030
• after 30 a		0.67[b]	1.930

[a] after 9 years [b] after 29 years

Thus, the BSK 3 concept also appears to be an appropriate solution for the emplacement of all types of heat-generating radioactive waste with the same kind of equipment. The choice of what system should be used will essentially be influenced by the still pending results of safety analyses of the whole disposal system.

Development of a New Disposal Technology

In view of these advantages, an R&D project with financial support from the German Federal Government and the German nuclear industry was recently launched to develop and test the systems and components for the transport, handling and disposal of BSK 3 canisters. The main objective is to demonstrate the functionality and reliability of the equipment and to obtain the data and information required for licensing this new back-end technology.

The project was also embedded into ESDRED (Integrated Project Engineering Studies and Demonstration of Repository Designs), a larger effort with thirteen partner organizations from nine European countries financially supported by the European Commission [3, 4] in the context of the EURATOM 6th Framework Program.

The system developed by DBE TECHNOLOGY GmbH[1] in cooperation with GNS and equipment manufacturers for handling and disposing BSK 3 canisters comprises: 1) a transfer cask which provides appropriate shielding during transport and disposal, 2) a transport unit consisting of mining locomotive and transport cart, and 3) an emplacement device. Fig 12 outlines the components of the entire transport and emplacement system in an underground emplacement drift.

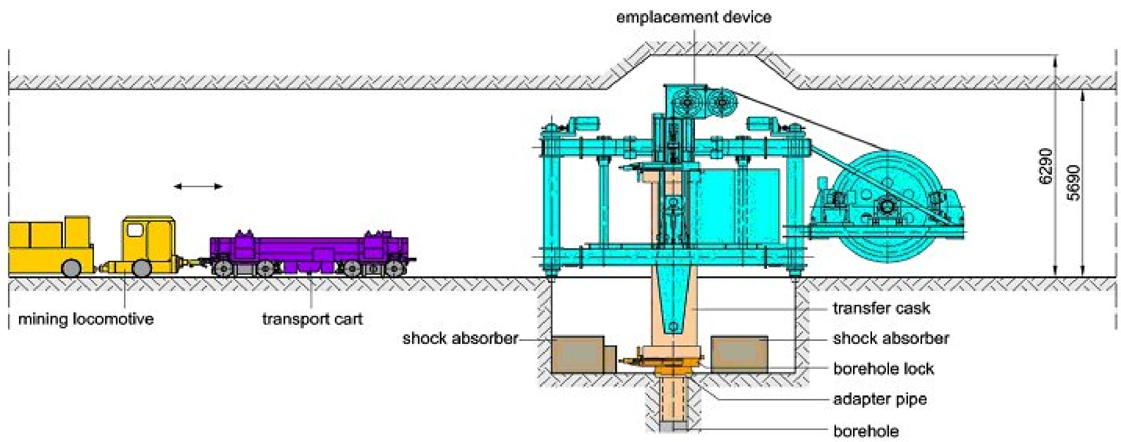


Fig. 12. Outline of the BSK 3 disposal system

The BSK 3 canister is inserted into the transfer cask in a hot cell at the surface, for instance at the PKA, shipped to the repository, hoisted to underground on the transport cart, and towed into the disposal drift. The emplacement device, previously positioned on top of the emplacement borehole, will carry out the disposal operation as described in detail below.

The BSK 3 Disposal System Components

For the demonstration tests a BSK 3 canister mock-up was procured, with the geometry and weight of the original but without radioactive material content. The BSK 3 dummy canister, Fig. 13, was manufactured and delivered to the test facility at Landesbergen in early 2008.

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[1] For statutory reasons all R&D work after 2000 was assigned to DBE TECHNOLOGY GmbH, a subsidiary of DBE mbH, the German Company for the Construction and Operation of Repositories for Waste, Ltd.

Fig. 13: BSK 3 canister mock-up

The transfer cask, Fig 14, is designed to provide mechanical strength and gamma and neutron radiation protection to allow workers to approach the cask in case equipment repair becomes necessary. The transfer cask body is a thick-walled cylinder made of nodular graphite cast iron (GJS). Neutron moderation and shielding is provided by polyethylene. Two locks made of stainless steel are screwed to the cask body. The flat slide latches integrated into the locks work like drawers and run in slide bars. When in the locked position, the flat slide latch is kept in place by two locking bolts set into the sidewalls. Fig 15 shows the transfer cask during manufacturing.

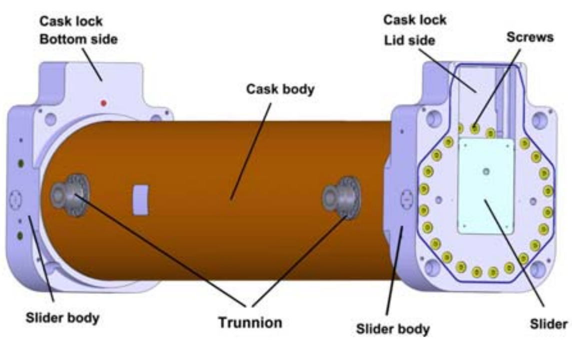

Fig. 14. Transfer cask **Fig. 15. Transfer cask during manufacturing**

The transfer cask is not fitted with a mechanism to operate the locks. Lock opening and closing is carried out at the base by the borehole lock mechanism and at the lid by the emplacement device (shielding cover). The emplacement device is equipped with all means for safe transfer cask handling and BSK 3 canister disposal.

In the course of a disposal sequence the BSK 3 canister is shipped inside the transfer cask on the transport cart to the emplacement drift at the determined position on top of an emplacement borehole. The transfer cask is then lifted off the transport cart by the emplacement device and turned into upright position after removing the transport cart. In the next step, the cask is lowered onto the borehole lock and locked in position. The lock at the transfer cask base and the borehole lock are opened, and the BSK 3 canister – held by the canister grapple of the lifting gear – is lowered into the planned final position inside the borehole. The canister grapple is then removed and the transfer cask and the borehole lock closed. After turning the transfer cask back into horizontal position, the transport cart is positioned again under the emplacement device and the transfer cask is placed on the cart. Finally, the transport cart with the transfer cask are driven out of the emplacement drift and back to the surface for reloading.

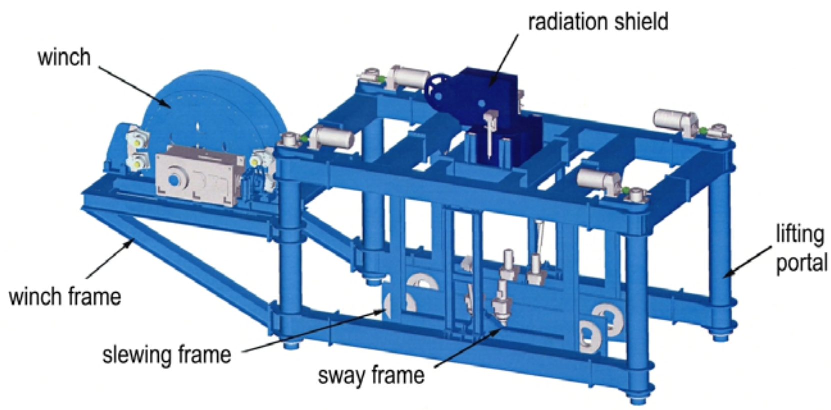

Fig. 16. Emplacement device outline

The emplacement device consists of the following main units: lifting gantry, flap-frame with controls, swivel gear, canister-lifting gear including hoist cable and lifting tackle and a shielding cover. It is shown in outline in Fig 16 and in the manufacturing workshop in Fig 17.

Fig. 17. Emplacement device in the manufacturing workshop

The emplacement device is 12.2 m long, 4.7 m wide, and up to 6.5 m high. As manufactured and assembled in the subcontractor's workshop it weights 66 t.

Further elements of the systems manufactured for testing include the borehole lock and the new transport cart. An outline of the borehole lock is shown in Fig 18. The new transport cart is shown in Fig 19.

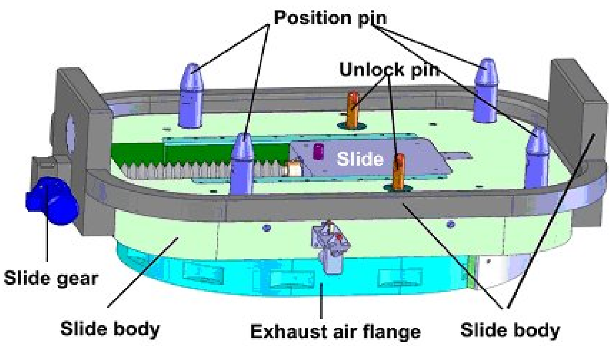

Fig. 18. Disposal borehole lock **Fig. 19. New transport cart**

The cart was fully redesigned by DBE TECHNOLOGY to overcome the previously mentioned tendency of the original cart for the POLLUX® system to derail. The new transport cart has a net weight of 10 t, a length of 6.15 m, a width of 1.49 m and, unloaded, is 1.4 m high. The gauge was selected to 1.99 m in order to allow the transfer cask to be swiveled into upright position between the rails.

The BSK 3 System Test Program

For practical reasons, it was decided to perform the demonstration tests in the same surface facility as the previously mentioned tests for the reference system, a rented former turbine hall of a power station in Landesbergen, near Hanover, in the Northern German state of Lower-Saxony. This building provides the possibility to simulate the emplacement process of a BSK 3 canister in a vertical borehole. The test facility is shown in Fig. 20.

At the start of the project, all new components of this BSK 3 system were designed in detail and external experts evaluated and approved the drawings and reports. After the competitive procurement process, the components were manufactured prior to the spring of 2008. Construction work to set up the test facility was carried out from February to April 2008. The components of the emplacement system were assembled there at 10 m above the ground floor. A 10-m long vertical steel metal casing simulates the emplacement borehole. For the test program, the BSK 3 canister is lowered down by the grapple of the emplacement device and, unlike in a real repository, is removed again thereafter for the next test run.

Fig. 20. BSK 3 system test facility

The transport cart and the battery-driven locomotive were delivered to the test site in April 2008. With delivery of the emplacement device in May and the transfer cask and the borehole lock in June 2008, all components were available at the test site. After acceptance of the individual components on site during the summer, the demonstration program, which is carried out in two shifts, started in July and is anticipated to last until the middle of 2009.

The test program comprises 1) demonstration tests, 2) simulation tests, and 3) tests to resolve operational disturbances. In total, approximately 1000 complete emplacement cycles will be carried out at the end of the test program in order to obtain information on the reliability of the entire system and of each component. With this, the necessary information will be available to demonstrate the safety and reliability of the system and to allow a detailed comparison of the reference POLLUX® concept with the novel BSK 3 disposal system.

OUTLOOK AND CONCLUSIONS

Some years after the demonstration of all the elements of the German reference concept for spent fuel disposal, a new, alternative system has been proposed, and is now being comprehensively tested. In addition to this, a feasibility study focusing on the direct emplacement of large transport and storage casks is currently being carried out. It can be summarized therefore that in spite of the standstill in regard to the future HLW repository site Germany has experienced during recent years, conceptual work taking into account the whole line from interim storage to disposal is still going on.

With the present test facility the reliability of the new BSK 3 emplacement system will be demonstrated by a large number of tests. Additional testing to determine data on probabilities of occurrences of failures, as well as to develop ways and means to resolve malfunctions or failures, will complement this R&D effort, thus allowing conclusions to be drawn for potential further improvements and for a later industrial application of this equipment in the repository.

After the end of this project, with the BSK 3 and the POLLUX® system, Germany will – from a technical point of view - have comprehensively tested aboveground both: the reference system for spent fuel and HLW disposal as well the BSK 3 system. Further unique know-how and experience on nuclear grade equipment development, procurement, and testing will have been obtained as well as the data and information needed for the licensing procedure. Both systems are still pending the industrial feasibility of the conditioning concept and the availability of final site acceptance criteria. However, from a mere technical point of view, with emphasis on handling requirements, all systems and equipment needed to run a future repository for HLW and spent fuel will be available for their future use.

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