PRELIMINARY RESULTS OF THE SYSTEMS ANALYSIS DUAL-PURPOSE REPOSITORY

R. Papp, K. D. Closs, W. Bechthold
Kernforschungszentrum Karlsruhe
H. J. Engelmann, B. Hartje
Deutsche Gesellschaft zum Bau und Betrieb
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ABSTRACT

The Gorleben salt dome in northern Germany is being explored so that its suitability to host a mined repository for heat-generating waste can be determined by the beginning of next century. While the disposal concept considered since the beginning of repository planning has been dealing only with reprocessing waste and 300-m-deep boreholes, current studies include both reprocessing waste and spent fuel with 300-m-boreholes as well as horizontal drifts as the basic components of the emplacement concepts. Packaging of all heat-generating waste and spent fuel in a single type of cask, referred to as POLLUX, requires advanced intermediate-level waste (ILW) treatment, thereby drastically reducing the total number of packages involved. Use of the POLLUX cask makes drift emplacement mandatory. In this case, due to the small number of packages, the occupational dose in the repository and during shipments is slowest among the alternatives considered. But also with respect to other aspects such as area requirement in the repository and cost, drift emplacement in conjunction with advanced ILW technology constitutes a highly competitive waste management option.

INTRODUCTION

At the occasion of last year's Tucson Conference a detailed account of the progress made in the FR Germany with respect to waste management was given (1). Therefore, it may suffice to characterize the major current efforts to complete the nuclear waste management system in the FR Germany by the following facts: Construction of the Wackersdorf fuel-reprocessing plant has been going on for four years, with completion still planned for the mid-1990s; civil engineering at the Gorleben pilot plant for conditioning of spent fuel and different sorts of waste will most likely begin during 1989; one 1,500-MT-interim storage facility (Gorleben) is about to operate while the second one (Aahaus) is under construction; the former iron-ore mine Konrad is expected to have an operating license awarded by the early 1990s for disposal of non-heat-generating waste; and finally, after the standstill caused by the 1987 accident, shaft sinking was resumed this January, to explore the suitability of the Gorleben salt dome to host a repository for heat-generating waste.

Besides these construction activities and accompanying R&D that consists in modeling and experimenting in above-ground and underground laboratories, an effort dubbed Systems Analysis Dual Purpose Repository is made to gather information from the relevant parts of the waste management system in order to, first, make interdependencies visible and, second, have a planning tool on hand. By that, technical, economical, and safety-related aspects of the waste form, of package design, storage and transport, and emplacement modes can be studied to better understand interrelationships. The final goal of this endeavor is to have a well-balanced waste management system ready for implementation by the time licensing documents for the federal repository will be submitted for approval. This effort is focusing on the Gorleben salt dome which, depending on the results of suitability studies, is to accommodate both reprocessing waste and spent fuel. This task has its origin in the Federal Government's decision of 1985 to adhere to fuel-reprocessing as the reference waste management route but to develop direct disposal of spent fuel as back-up solution.

The systems analysis is subdivided in two phases, with phase I scheduled to be concluded by the second half of 1989. It is characterized by an approach which, at least at the beginning, was quite generic in nature. No site-specific features of the prospective repository were initially taken into account. It was not before the end of 1987 that PTB, the German federal lead agency responsible for repository planning, strongly recommended that the information acquired during the concurrent exploration of the Gorleben salt dome be included. Another simplification was made with respect to the nuclear energy scenario: A constant annual amount of 700 MT of spent fuel is being assumed, with 500 MT going through the reprocessing plant, and the remaining 200 MT to be conditioned for direct disposal. This total of 700 MT/yr will be maintained through all of phase I, but allows for a variation of the spent fuel streams being destined for reprocessing and direct disposal, respectively. Discussions concerning a second project phase will start in late 1989 and, most likely, the conception of a rigid annual amount will give way to an approach with actual annual waste streams in the FR Germany, thereby including intermediate-level waste with negligible heat generation and low-level waste, waste streams totally omitted in phase I.

Before presenting preliminary findings, the main technical features of the systems under consideration will be described to such an extent that the essence can be understood without burdening the reader with details. An in-depth description is given in Ref. 2.

THE WASTE MANAGEMENT SYSTEM

The Waste Package

The most impressive single item in this system by its sheer dimensions of 5.5 m in length, a diameter of 1.5 m and a weight of about 65 MT is the cask dubbed POLLUX (3) which can hold eight consolidated PWR fuel assemblies plus their compacted skeletons. This cask is, firstly, Type

B(U) qualified, i.e., through a cast iron overpack it complies with transport regulations; secondly, it is designed to withstand the lithostatic pressure at a depth of about 1,000 m in the repository in salt. That all makes it suitable for shipment, storage, and disposal of spent fuel.

High-level waste (HLW) from reprocessing is vitrified and filled into stainless steel canisters with outer dimensions of 0.43 m (diameter) and 1.34 m (length), each holding the equivalent of 1.15 MT of heavy metal (HM). Canisters with the same outer dimensions but with a wall thickness of 5 cm to function as a long-term barrier are used as a back-up concept for spent fuel disposal. This concept requires the fuel pins of half an LWR fuel assembly (~ 1/4 MT HM), after separation from the structural material, to be cut into 1-m pieces and inserted into the canister.

The 400-l-drum is a package type of many uses. Heat-generating intermediate-level waste, ILW, from two processes is considered in this analysis: Feed clarification sludge, hulls, and structural material of fuel assemblies arising from fuel-reprocessing can be mixed with cement and filled into the 400-l-drum. In the case of the Wackersdorf reprocessing facility, 1,530 drums will accommodate ILW stemming from 500 MT/yr (~ 0.3 MT/drum). THe same process can be applied to the structural material originating in the aforementioned back-up concept for spent fuel disposal (2 MT/drum). In both cases the cemented waste is filled in 400-l-drums. So far, only spent LWR fuel and the ensuing waste forms have been discussed but in the wake of the 1985 policy decision earlier alluded to, the Federal Government had also decreed, first, to stop further work aiming at reprocessing of spent fuel from the German high-temperature reactor (HTR) program and, second, to dispose of that fuel directly. It was, therefore, agreed to include one million (~ 1.2 GW_e) of these tennis-ball sized fuel spheres in the analysis whereby the 400-l-waste drum holding 1,800 spheres has been defined as the reference package for disposal (4).

There is one interesting detail which deserves mention even in this summary description: Advanced conditioning technology is being considered for ILW. According to that, Zircaloy hulls as well as fuel assembly hardware are compacted, feed clarification sludge is immobilized in a ceramic matrix, thereby making it much more heat-resistant than conventionally-conditioned ILW which can only endure 100oC. In addition, the number of ILW packages is reduced considerably (by about a factor of 6). Both products can be packaged in canisters the size of the HLW-canister and coemplacement with hot HLW and spent LWR fuel is made possible.

Emplacement Concepts

In Table I three aspects are highlighted: In the lower portion the outer dimensions of the packages described above, including the one referred to as "shielding," which is designed to carry four ILW-drums in the repository. Second, the waste forms are listed with their associated main package alternatives. An alternative package for spent HTR fuel is a slightly modified POLLUX cask holding *12,600 spherical fuel* elements. Another version of the POLLUX can hold six canisters with vitrified HLW plus three canisters with ILW conditioned in an advanced way. Finally, the ensuing emplacement concepts are given in Table I, horizontal drifts and 300-m-deep boreholes with two different diameters (0.7 and 1.15 m).

The emplacement concept that has been pursued in the FR Germany since the beginning of repository planning is the one centering around the vertical borehole being drilled in a mined repository from a depth of 870 down to 1,170 m. In the course of the R&D-work for direct disposal of spent fuel, horizontal emplacement in drifts was favored for the associated heavy packages like the POLLUX cask. Thus, the Systems Analysis Dual-Purpose Repository generally comprises both elements - emplacement drifts and vertical boreholes - but concepts exclusively based on drift or borehole emplacement are also considered.

As important design bases for the repository, the requirements are that the temperatures at any time after emplacement be kept below 200°C in the package-salt interface and below 100°C inside the ILW package, unless ILW is conditioned in an advanced way. In the latter case one can do without that restriction, making coemplacement of ILW and high-level waste possible. The relevant spacings between boreholes, drifts etc. are determined by these thermal constraints. To characterize orders of magnitude, the 200°C-design basis entails distances between neighboring boreholes filled with HLW canisters of about 50 m, between parallel emplacement drifts for POLLUX casks of 14 m. The minimum borehole distance in the case of ILW or HTR fuel is not determined by these thermal constraints but reflects the state-of-the-art in dry drilling of 1-m-diam 300-m-deep boreholes.

RESULTS

Repository Design

The first step of designing the repository consists in near-field calculations (5), taking the aforementioned thermal constraints into account. As a result, area requirements in the salt dome like the ones in the third column of Table II are obtained for the scenario of 700 MT/yr of spent LWR fuel referred to earlier, with 500 MT/yr going through reprocessing and 200 MT being disposed of directly. The age of spent LWR fuel and of vitrified HLW upon disposal is 30 years with an additional time span of ten years that has elapsed between the fuel discharge from the LWR and reprocessing. There is one concept that stands out from the others, three-level drift emplacement (DT) (2.0 ha/a, almost 60 percent of which are attributable to ILW in the shielded containers holding four 400-l-drums each). If, however, advanced conditioning of ILW is applied, making joint packaging of HLW and ILW possible (see Table I), the number of packages and, consequently, the annual area requirement is markedly reduced (0.92 ha/a). In the case of pure borehole emplacement (BL, BL*) this reduction is not as pronounced but through this "thermal dilution" the age of vitrified HLW upon emplacement could be shortened by 20-25 years without violating thermal boundary conditions.

Table I

Waste Package and Repository Emplacement Characteristics

Waste Form	Package	Emplacement Vertical 300m-Borehole	Horiz. Drift	
		a	b	
	Canister	X		
Vitrified HLW				
	POLLUX a 6 canisters			X
	POLLUX			X
Spent LWR fuel				
	Canister	X		
	400-l-drum		X	
Spent HTR fuel				
	POLLUX 12,600[c]			X
	400-l-drum		X	
Cemented ILW				
	Shielding a 4 drums			X
	Canister	X		
Advanced ILW				
	POLLUX a 6 HLW + 3 ILW canisters			X

	Canister	**400lDrum**	**POLLUX Cask**	**Shielding**
Length (m)	1.34	1.14	5.46	5.16
Outer diam. (m)	0.43	0.78	1.54	1.44

a 0.7 0 b 1.15 m 0 c 12,600 HTR fuel spheres

In addition to the 200°C-temperature constraint for the near-field, the thermomechanical stability of the salt barrier has to be confirmed by far-field calculations. One concern is the formation of thermally induced fissures resulting from tensile stress at the top of the salt dome, thereby opening pathways to intrusion of water. Only two-dimensional calculations have been performed so far for a model of the Gorleben salt dome (6). THe results exhibit tensile stress of about 1 MPA ± 20% only if the lowest steady-state creep capacity found with Gorleben rock salt samples is

Table II

Repository Area Requirement (ha/a) for Various Repository Concepts

Emplacement Concept	Packages per Year	200°C Design Basis	Detailed Engineering
BD1	2,566	1.61	2.05
BD2	2,566	1.33	1.87
BL	3,369	1.29	1.58
BL*	2,204	1.03	-
DT	584	2.00	2.51
DT*	205	0.92	1.13

BL: pure borehole, DT: pure drift, BD: borehole + drift, *advanced ILW

assumed in the calculations. Among the concepts considered, tensile stress was at the upper bound for concept BD2, where the temperature maximum occurs at the 870-m-horizon; the temperature maximum is at greater depth for the other concepts.

These thermal calculations are the prerequisites for more detailed repository engineering which, for a number of reasons, entails area requirements that are larger by a margin of 20-40% than the ones based on the 200°C-criterion alone. These reasons are those which detailed engineering has to take into account:

safety pillars between drifts which have to be kept open over extended periods of time.

spacings of about 75 m between "hot" emplacement panels for spent LWR fuel and/or HLW and "cold" panels for ILW in case the temperature has to be kept below 100°C.

In addition, future repository operation can be facilitated through systematic planning like:

subdividing the disposal area in emplacement panels, each of which can be serviced from one access drift and where only a single type of package is emplaced, thereby enabling use of a single emplacement technology.

applying retreat mining, i.e., first filling up the panels most distant from the shafts, thereby isolating appreciable quantities of waste from ongoing mining operations by means of panel seals.

Figures 1 and 2 show layouts of mined repositories resulting from such repository design, one featuring boreholes as well as emplacement drifts (BD1), the other three-level drift emplacement (DT*).

Radiological Safety

As stressed in Table II, the numbers of packages to be handled lie within a wide range for the different repository

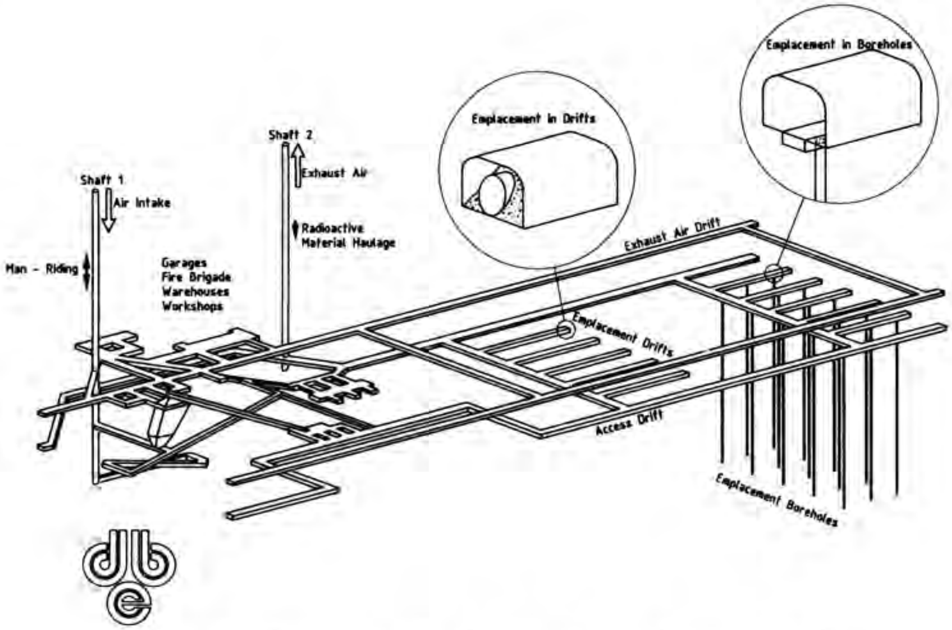

Fig. 1. Drift and Borehold Repository Concept (BD1).

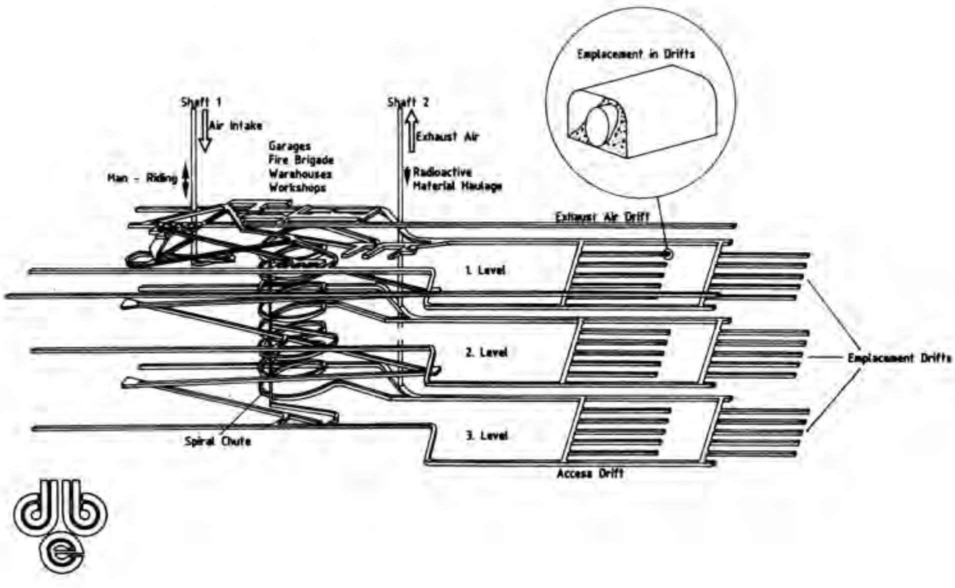

Fig. 2. Three-Level Drift Emplacement Concept (DT*).

concepts, with varying consequences for operational aspects. The borehole concepts, BL and BL*, require not only the most extensive but also the most complex handling efforts due to repeated reloading steps associated with disposal of drums and canisters in boreholes. In Table III, the approximate annual occupational doses for various emplacement concepts are given. Pure drift emplacement scores best with an additional advantage in case advanced ILW technology is applied.

Table III

Occupational Dose (Pers-mSv/a) for Various Repository Concepts

Emplacement Concept	Surface Installations	Underground Installations	Total Repository
BD1/BD2	30	18	48
BL	36	24	60
BL*	18	15	33
DT	12	4	16
DT*	4	2	6

(Source: DBE)

Apart from these doses due to direct radiation, additional radiation exposure resulting from radionuclide releases could occur during normal operation and accidents. While this is possible with waste drums and thin-walled canisters, it can practically be ruled out for pure drift emplacement concepts where the waste form is contained in thick-walled and welded casks. The Type B(U) qualification of the POLLUX cask makes sure that through its design it can cope with all potentially possible impacts during handling operations in the repository.

Besides doses during operation, long-term safety analysis is also of concern in the Systems Analysis Dual-Purpose Repository. This type of analysis is still in its preparatory phase and, upon this writing, only a few general ideas can be developed.

First, volumes excavated during mining should be kept as small as possible. In Table IV, volumes are compared for the various emplacement concepts. It is noteworthy that in all cases except for pure drift emplacement the volume mined during the underground exploration of the salt dome is of the same order of magnitude as during repository operation. The volumes are highest for the drift emplacement concepts, but, again, the positive effect of advanced ILW treatment is evident. A remedial measure that could possibly be taken in the case of concept DT*, three-level drift emplacement, is the conversion into a two-level concept, thereby further reducing the total volume to be mined.

Best use of the plasticity of rock salt can be made in areas where the temperature and, consequently, the room closure rate are high. In other words, long-term safety would be enhanced if all waste were emplaced in hot emplacement panels. Boreholes filled with vitrified HLW or spent fuel take some months before they are completely sealed due to salt creep. For emplacement drifts this process is much slower, even at high temperatures, and lasts a few decades. On the other hand, in boreholes for drummed waste the temperatures are much lower (< 100°C) and the voids surrounding the packages are closed much more slowly.

For the time being these more or less qualitative statements can only give some hints with respect to long-term safety and are no substitute for detailed modeling of intrusion of brine and its subsequent fate.

Table IV

Mined Volumes (1,000 m^3) for Repository Concepts

		Repository		
Emplacement Concept	Repository Exploration	Emplacement Openings	Infrastructure	Total Operation
BD1	913	1,130	482	1,612
BD2	"	1,147	436	1,583
BL	"	995	352	1,347
DT	"	3,330	1,603	4,933
DT*	"	1,311	902	2,213

(Source: DBE)

Economy

A first attempt at an economic evaluation of the various concepts is founded on cost estimates for both the repositories and the containers involved. The overall costs for the repository as given in Table V vary only by less than 10%, with drift emplacement having an economic edge over the competing concepts. This is mainly due to the fact that with pure drift emplacement lower costs for seal construction and renovation of the machinery are incurred over the 50 years of repository operation. It has to be emphasized that in Table V costs for waste producing negligible heat are not included. Table V, therefore, does not reflect the actual cost situation of the Gorleben repository.

In order to supplement repository costs by costs for canisters and spent fuel conditioning the data listed in Table VI were used. High costs are caused through POLLUXI-type casks. On the other hand, in this analysis costs were charged neither for packaging of vitrified HLW and ILW nor for conditioning of ILW.

The unit costs add up to total costs as presented in Fig. 3 where also the repository is included. Even through this approximate analysis, which does not allow for cost escalation, interest rates, and other effects, it is quite evident that, most likely, drift emplacement becomes only competitive through advanced treatment of ILW. In addition, the results for pure drift emplacement are kind of distorted by the fact that the energy density of spent fuel in HTR-POLLUXes is more than one order of magnitude smaller than in an LWR-POLLUX - the HTR-POLLUX carries almost nothing but

Table V

Cost Components (Mill.$)[a] of Repository Concepts

Repository Concepts	Exploration (1978-2000)	Repository Construction (2001-2005)	50Year Repository Operation	Total Cost
BD1	907	555	1,672	3,134
BD2	"	553	1,687	3,147
BL	"	542	1,672	3,121
DT	"	554	1,522	2,983
DT*	"	538	1,451	2,896

[a]only valid for this comparative analysis (Source: DBE)

Table VI

Basic Cost Data for Packaging Spent Fuel and Waste

200 MT/a-Spent Fuel Conditioning Plant (Mill.$)[b]:

	Reference[c]	Backup[d]
Construction	370	430
Operation (1/a)	8.8	8.8
	Container (1,000 $):	
LWRPOLLUX 400	HTRPOLLUX 170	LWRCanister 40
HLWPOLLUX 200		ILWShielding 90

[b]1.75 DM/$ [c]consolidated fuel assemblies [d]cutting of fuel rods

graphite (94%) - while they give rise to almost 30% of the total container costs (concept DT*). It can be expected, however, that through inclusion of costs for storage prior to disposal the drift concept DT* will score better economically: Utilization of additional CASTOR-type transport and storage casks is mandatory in all cases except pure drift emplacement which can manage exclusively with the POLLUX cask for transport, storage, and disposal.

CONCLUSIONS

It can be concluded that licensable repositories concepts for both reprocessing waste and spent fuel are conceivable with borehole and drift emplacement as well as a mixture of both as viable options. Pure drift concepts for heavy packages lend themselves to standardized handling and emplacement technique and, consequently, low occupational doses. But they become fully competitive with the other concepts only if advanced ILW technology is

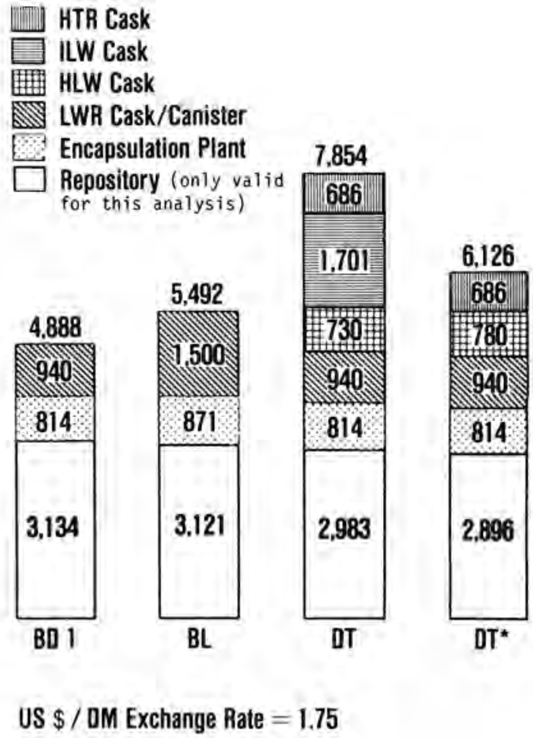

Fig. 3. Repository and Packaging Costs (Mill.$).

employed which paves the way to rely exclusively on the POLLUX cask system for storage, transport, and disposal.

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