RESULTS OF THE SYSTEM ANALYSIS DUAL-PURPOSE REPOSITORY

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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. A substantial number of disposal concepts including above-ground waste treatment and cask alternatives have been designed and evaluated by means of a host of selection criteria belonging to seven different criteria fields. By this evaluation it is not only recommended to further pursue the joint borehole and drift concept (BD1) as well as drift concepts that include advanced ILW treatment but it is also identified which areas require additional R&D.

INTRODUCTION

The Systems Analysis Dual-Purpose Repository includes both planning and evaluation of waste management alternatives whereby emphasis is laid on the repository. According to the German Atomic Energy Act spent nuclear fuel is to be disposed of directly in ann established reprocessing technology is either unavailable or economically not justifiable. This is the case for LWR fuel manufactured from reprocessed uranium, for high burn-up and MOX fuel as well as all fuel from the German high-temperature reactor (HTR) program. Consequently, the concurrence of reprocessing waste and spent fuel has to be included in the repository planning. For the present analysis, a quite general approach has been adopted by varying within a wide range the fraction of spent LWR fuel destined for direct disposal. A reference case was chosen, characterized by a ratio of 500/200, describing a situation in which 500 MT of spent LWR fuel out of a total of 700 MT are reprocessed annually, while 200 MT are disposed of directly; in addition, a constant annual amount of 10^6 spherical fuel elements from the HTR-program (approx. 1,200 MW) are subject to direct disposal. Further details have been reported at the occasion of last year's Tucson Conference (1).

THE WASTE AND SPENT FUEL MANAGEMENT SYSTEM

Before addressing the question of how most suitable waste management system alternatives have been selected, the main technical features of the alternatives are described to such an extent that the essence can be understood without burdening the reader with details. An in-depth description is given in (2). In Fig. 1 an attempt has been made to sketch the alternatives, starting with the four products, reprocessing waste and spent fuel, and ending up in the repository. The reference design for both reprocessing waste and spent fuel is emphasized by the bold lines. For vitrified high-level waste, HLW, the reference case is the 43-cm-diameter canister which is emplaced in 300-m-deep boreholes which applies, as an example, to disposal concepts BD (the concept combining vertical borehole and horizontal drift emplacement) and concept B (the emplacement concept that relies on borehole emplacement for all waste forms considered).

In the reference case of direct disposal of spent LWR fuel a newly developed cask dubbed POLLUX holds the consolidated rods from eight spent fuel assemblies (Fig. 2) and has a total weight of 65 MT. It is only suited for horizontal emplacement in drifts like in the case of disposal concepts BD and D, the latter being the concept exclusively based on emplacement in drifts for the four products.

The alternative to spent fuel packaging in the large-size POLLUX is accommodation of only 1/2 LWR fuel assembly in a small canister with the same outer dimensions as the canister for vitrified HLW and emplacement in vertical, 300-m-deep boreholes (concept B). As a side effect, secondary waste is generated during packaging of spent fuel; this intermediate-level waste (ILW) is ether cemented and filled in 400-l-drums or compacted in a 43-cm-diameter canister (dotted line).

The alternative way for HLW is the loading of six canisters into a large-size POLLUX-cask and the emplacement in drifts (disposal concept D. For heat-generating ILW such as hulls and feed clarification sludge, cementation in a 400-l-drum and borehole emplacement is the reference concept (concepts B and BD). One alternative is a "four-pack" of four drums in a so-called "lost" shielding that is suitable for drift emplacement (concept D); another alternative features advanced conditioning of ILW (reprocessing waste), i.e., compaction of Zircalloy hulls as well as fuel assembly hardware, immobilization of feed clarification sludge in a ceramic matrix (the dotted line in Fig. 1), and loading into a 43-cm-diameter canister. This type of advanced treatment increases the heat-resistance of ILW so that coemplacement with HLW and spent LWR fuel be-

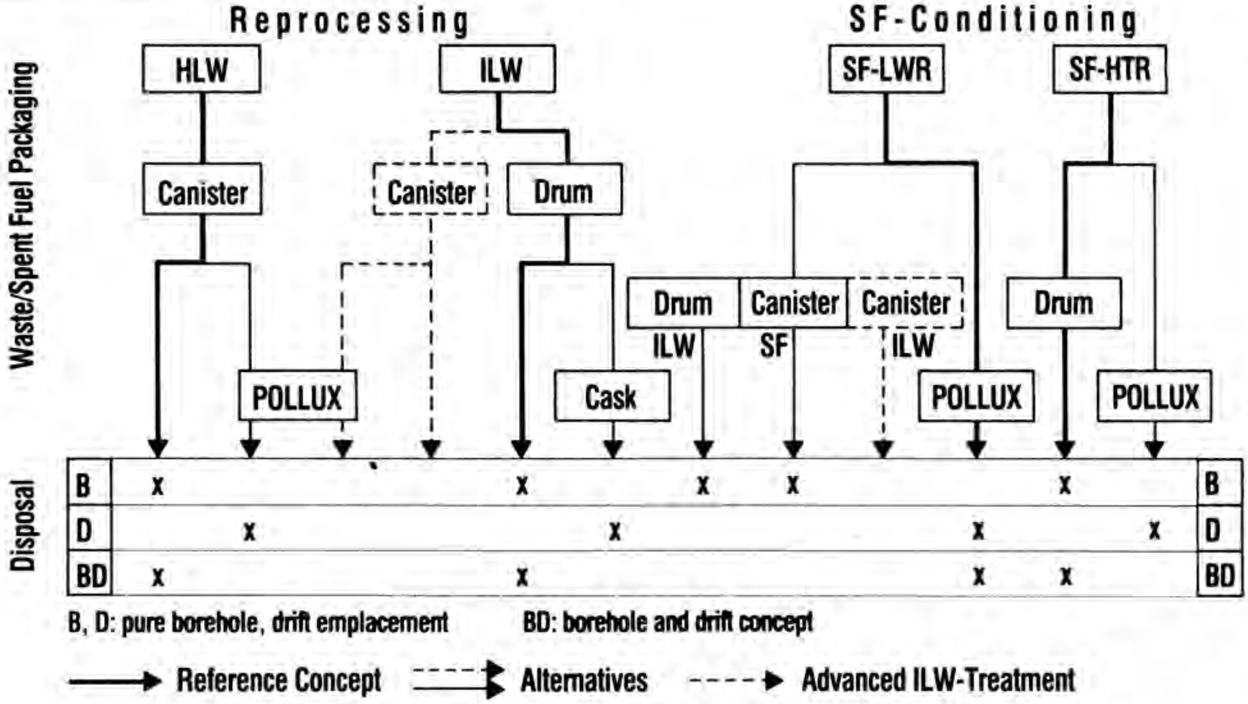


Fig. 1. Reprocessing Waste and Spent Fuel Management Alternatives

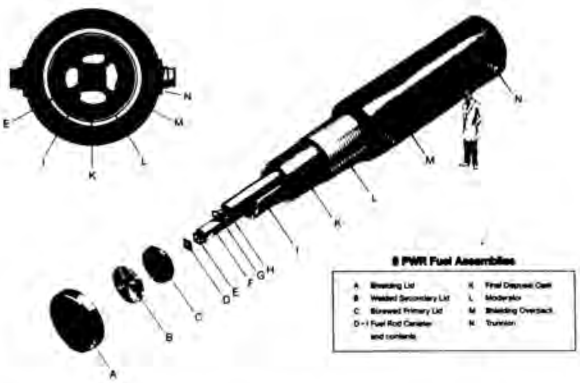


Fig. 2. POLLUX Spent LWR Fuel Disposal Cask

comes possible. In addition, the number of ILW-packages is reduced considerably.

Finally, spent HTR-fuel spheres are filled in 400-l-drums or, as an alternative, in specially-designed POLLUX-casks thereby enabling drift emplacement. Altogether, for each of the four products considered, two types of reprocessing waste and of spent fuel, both borehole and drift emplacement are feasible. It is essential to take a closer look at the subsurface part of the system, at least the disposal concepts which played a major role in the selection process.

A maximum rock salt temperature of 200°C one basis for repository design resulted in distances of about 50 m between the hot boreholes filled with canistered HLW and spent fuel. These boreholes are characterized by the thin vertical lines in Fig. 3. Also, with the 200°C-design basis, the spacing between POLLUX-casks in drifts was determined. For the cooler repository sections accommodating cemented ILW and HTR fuel assemblies in 400-l-drums, a 25-m-distance between the boreholes served as the second design basis. As the diameter of the drums exceeds that of the small canisters, the borehole diameter in the cooler sections is larger and these boreholes are identifiable by the thicker vertical lines in Fig. 3.

Concepts BD1 and BD2 comprise both boreholes and drift emplacement. BD1 is distinguishable from BD2 in that spent LWR fuel in POLLUX-casks is an emplacement field that is separated from the borehole section. BD2, on the other hand, features a section that is common to borehole and drift emplacement with POLLUX-casks atop of boreholes for HLW, except for a small portion of the spent LWR fuel which is emplaced in a separate drift section. This common section for boreholes and drifts proves decisive for concept BD2 later on, when evaluating it from the viewpoint of safeguards.

Concepts B and D include only borehole and drift emplacement, respectively. The impact of advanced ILW treatment on the area *requirement in* the repository is demonstrated most impressively by comparing B and D with their respective modifications featuring advanced ILW treatment: In the case of B*, the pure borehole concept, the ILW can now be disposed of in the hot borehole section and the cold borehole section shrinks to the inevitable rest determined by the HTR spent fuel. In the case of pure

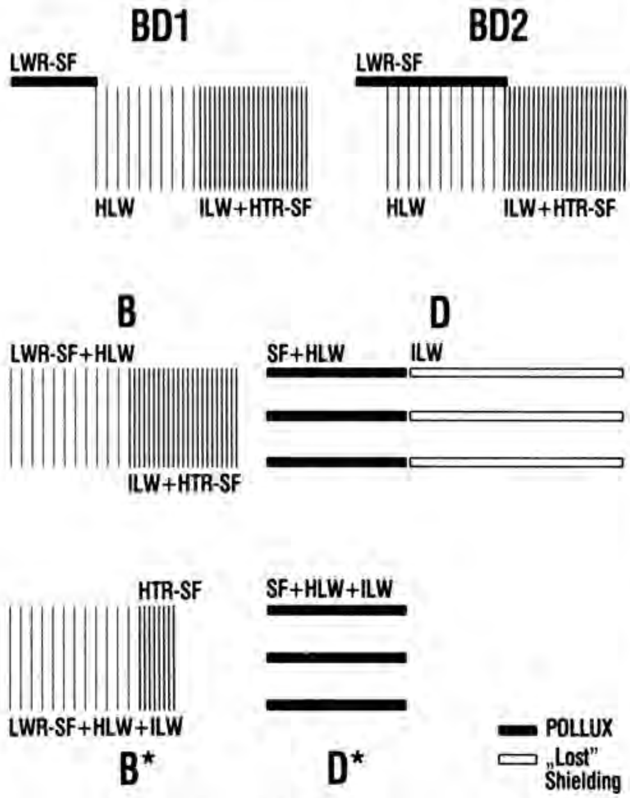


Fig. 3. Disposal Concepts

three-level drift emplacement, D*, this effect is even stronger; both the HTR fuel and the heat resistant ILW are now accommodated by POLLUX-casks, and concept D* can do totally without cold drift sections. The Systems Analysis Dual-Purpose Repository centered on these six concepts. Some analyses were also performed for additional concepts like BD3, BD1* and BD2* but this report is mainly restricted to the six concepts.

EVALUATION

The main purpose of this study was to determine an optimized system by choosing from among above-ground and underground concept variants which are generated by the aforementioned pre-disposal treatment as well as repository design alternatives. Seven fields of selection criteria (Table I) have been defined, with some fields, including ten or even more individual criteria. The selection procedure which consisted in two steps was accomplished by a group of experts: The first step was the assignment of weights to the individual criteria of a field according to the relative importance of the individual criteria; the second step the evaluation of the alternatives for each criterion by assigning points. For both the weights and the points, a scale ranging between one and ten was used. For each criterion, at least one of the alternatives was given ten points. Before presenting the overall score and the final selection of the most suitable concepts, those individual criteria should be addressed which (1) have been assigned relatively high weights and (2) reveal fairly clear distinctions between the competing concepts.

TABLE I

Selection Criteria Fields

I: Operating Safety

II: Status of Technology and Licensibility

III: Operational Aspects

IV: Utilization of Salt Dome

V: Long-Term Safety

VI: Economics

VII: Safeguards

According to that, two criteria dominate field 1, the operating safety of the repository (Table II): Mining safety during excavation and operation is crucial in the case of three-level drift emplacement (concepts D and D*) because the lower horizon was assumed to be at a depth of 1,170 m, 300 m below the upper horizon which is also the emplacement horizon of all other concepts. Room closure rates are specially high at the lowest horizon, while drifts and openings at the 870-m level show relatively small closure rates and the total volume of underground openings (which is highest for concept D) were used as a figure of merit yielding the score as given in Table II.

TABLE II

Criteria Dominating "Operational Safety"

• Mining Safety During Excavation and Operation:

Concept	BD1, BD2	B	D	D*
Evaluation (points)	9	10	5	7

• Routine and Accidental Release From Repository:

BD1, BD2, B	D	D*
6-7	9	10

Radioactive effluents from the repository are the second aspect dominating operational safety. During normal operation, they are determined by the cemented ILW in drums which mainly affects the borehole concept B while concepts with advanced ILW treatment such as D* are not affected at all. With regard to accidents, releases are highly unlikely in the case where qualified casks, such as the POLLUX, are employed but even the four-pack, i.e., the four-drums in a shielding, enhances mechanical integrity. All that explains why concepts including cemented ILW in boreholes score relatively low.

Criteria field II (Table III), status of technology, and licensibility, is controlled by two criteria: Licensing chances of disposal packages and the remaining R&D, requirements to further shaft hoisting technology. The licensing chances for an entire waste management concept are better if packages are part of the system which have special qualifications such as the POLLUX-cask. Therefore, concepts including drums are penalized by being awarded fewer points. As to the shaft hoisting equipment, borehole concepts score higher because their 40-t-hoisting capacity is state-of-the-art; on the other hand, concepts relying on 65-t-POLLUX-casks require a hoisting capacity of 85 t which is not fully developed yet. In addition, the borehole concept can take credit from the German Konrad repository from which technology can be transferred to the Gorleben project.

TABLE III

Criteria Dominating "Status of Technology and Licensibility"

- Licensing Chances of Disposal Packages:

BD1, BD2, B	D	D*
7-8	9	10

- R&D Requirements for Shaft Hoisting Equipment:

B	BD1, BD2, D, D*
10	6-8

The availability of the shaft hoisting and the waste handling equipment is lower for concepts including canisters because they require an above-ground hot cell which is an additional source of failure. Concerning the handling equipment underground, the number of components is a measure of the availability which, again, tends to be less favorable for borehole concepts. Therefore, pure drift concepts, D and D*, are assigned ten points while the other concepts, depending on the extend of borehole emplacement, score lower (Table IV). The second criterion pertaining to "operational aspects," the volume of salt piled up above-ground, is rated highest in this field because it affects the environment. This pile is largest for concept D, while the excavations are relatively small for the borehole concept.

TABLE IV

Criteria Dominating "Operational Aspects"

- Availability of Shaft Hoisting and Waste Handling Equipment:

BD1, BD2, B	D, D*
7-10	10

- Volume of Salt Pile:

BD1, BD2	B	D	D*
9	10	5	7

The utilization of the salt dome (criteria field IV) is determined by two criteria. The higher weight is given to the flexibility exhibited by the emplacement configuration, i.e., the adaptability to the rather complicated structure of the Gorleben salt dome as can be inferred from the ongoing site investigation. As flat emplacement concepts are judged more flexible, concepts D and D* are rated highest (Table V). The area requirement was viewed less crucial than the adaptability because the extent of suitable host rock, at least in the present stage of site investigation, does not seem to be the limiting factor. Apart from the one-level drift concept, D1, all concepts have a cross section of 300 m wide by 300 m deep that extends horizontally over an area as given in Fig. 4. This illustration does not only explain why the points were allocated to the concepts as given in Table V but highlights the advantage of advanced ILW treatment: B* is considerably smaller than B (pure borehole emplacement), but this space-saving effect is even more pronounced for pure three-level drift emplacement (D, D*). In addition, this figure shows that the space required by spent fuel is almost the same as if this spent fuel were reprocessed with subsequent disposal of the resultant HLW and ILW. For a given concept (e.g., B and D*), the transition from the ratio IE/DD equal 600/100 (i.e., 600 MT out of 700 are reprocessed) to IE/DD equal 200/500 brings about an area increase of only 15-20%, whereby part of this increase is due to the shorter pre-disposal cooling time (30 years versus 40 for HLW) and the higher burn-up of spent LWR-fuel destined for direct disposal (45 versus 40 GWd/MT).

TABLE V

Utilization of Salt Dome

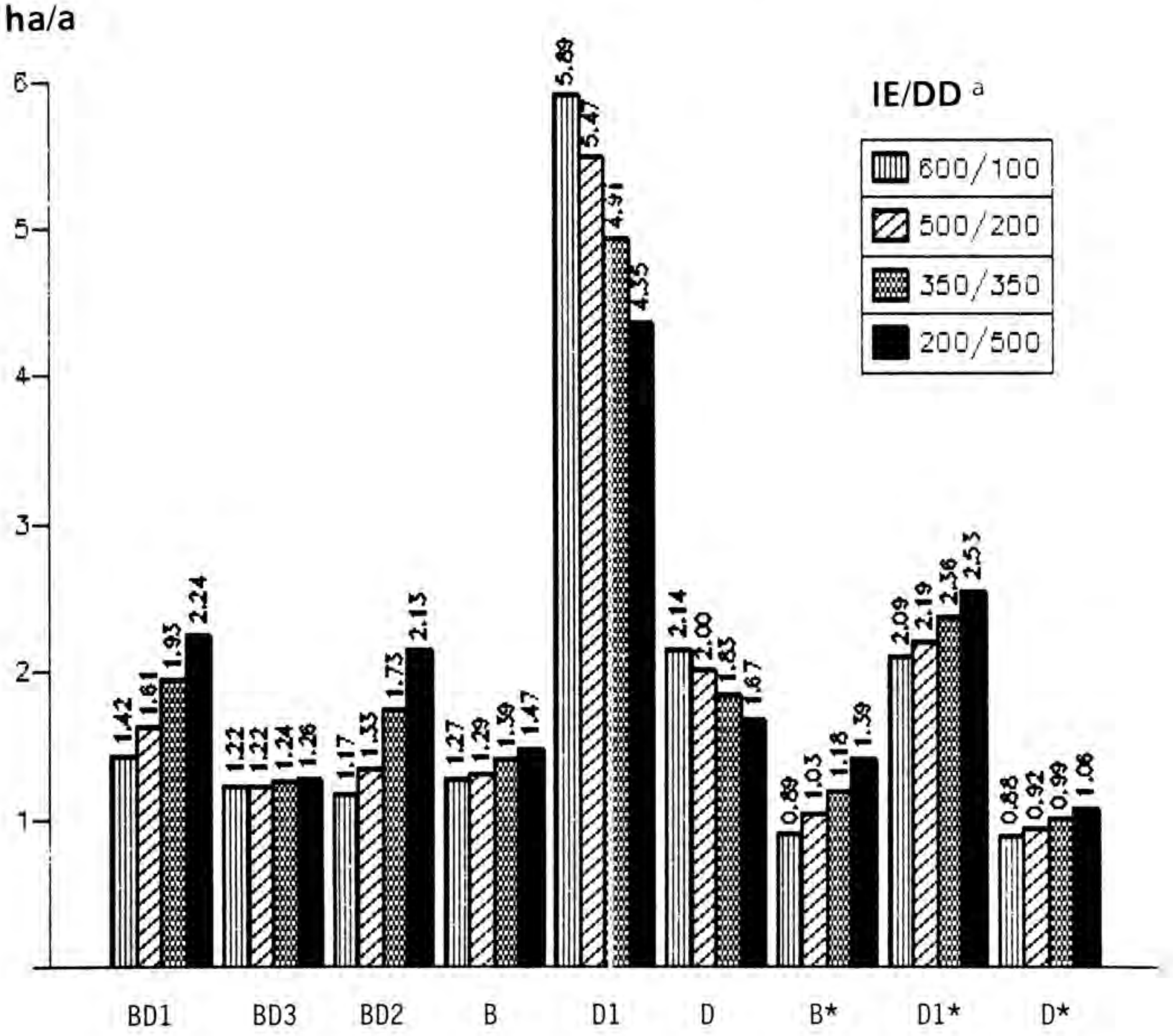
- Adaptibility With Respect to Geologic Structure:

BD1, BD2	B	D, D*
8	7	10

- Area Requirement for Disposal:

BD1	BD2	B	D	D*
6	7	8	4	10

With the criteria belonging to field V, long-term safety and repository performance are rated. 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. The results of far-field calculations exhibit tensile stress around 1 MPa only if the lowest steady-state creep capacity found with Gorleben rock salt samples is used in the calculations (2). Regarding tensile stress and the uplift of the repository surface, concepts including vertical boreholes do better than D and D* that rely exclusively on horizontal drifts (Table VI). The second aspect with clear distinctions between the competing concepts is the access of brine to the waste. This distinction results from remaining voids in boreholes and drifts but especially from the geometrical sequence of emplacement panels. To give an example, the "cold" ILW panel of concept D with its low room, closure rates is located next to the shaft; according to one accident scenario, a pathway is opened for brine via the main anhydrite, thereby reaching the ILW. As a consequence, concept D ranks very low, while concepts like BD1 and BD2 which include both borehole and drift emplacement score highest. Among the criteria of field V, the highest weight was assigned to the radiation exposure itself. Preliminary results suggest an evaluation as given in



a tons per year reprocessed/tons per year disposed of directly

Fig. 4. Repository Area Requirements for 700 MT LWR Fuel and 10^6 HTR Fuel Spheres.

Table VI with concepts that include vertical boreholes receiving ten points.

The evaluation from the viewpoint of economics is based on costs for packaging and disposal as presented in Fig. 5. Repository costs, exploration, construction, 50 years of operation, of the concepts considered differ only by a small margin; this is also true for ratios IE/DD that differ from the one of Fig. 5 (500/200). Concerning the encapsulation plant, higher costs are incurred through cutting LWR fuel rods and packaging in small canisters (concept B). In the case of the borehole concept the hatched area in Fig. 5, characterizing the canister costs, is also considerably higher than in all other cases. The canister costs are 1/10th of the POLLUX costs but the capacity is only 1/16th. For the drift concepts, D and D*, costs accrue from POLLUX-casks for vitrified HLW and HTR fuel spheres. If, in addition, the

ILW is not conditioned in an advanced way like with D, the "lost" shieldings for the drift emplacement of 400-l-drums cause a considerable cost increase.

TABLE VI
Long-Term Repository Performance

• Tensile Stress and Uplift in the Far-Field:			
BD1, BD2	B	D, D*	
8-10	9-10	7-8	
• Brine Intrusion:			
BD1, BD2	B	D	D*
10	9	1	8
• Radiological Dose to Man:			
BD1, BD2, B	D, D*		
10	7		

The evaluation of the concepts was finally based on the levelized costs with the amount of HTR fuel reduced to a more realistic 390,000 spheres per year, the discharge of a single HTR-500. This resulted in seven points for D, 9 for D* and B, 10 for BD1 and BD2.

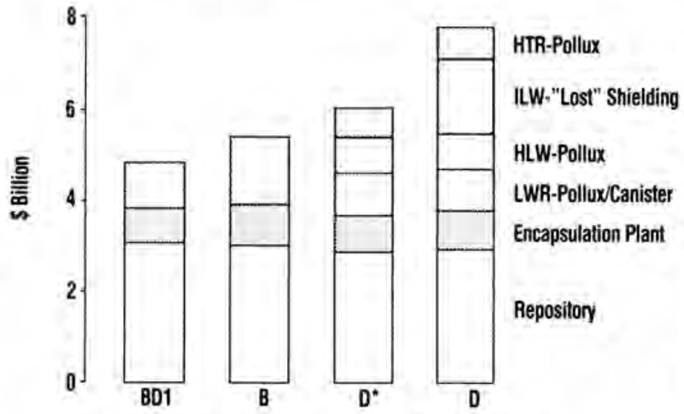


Fig. 5. Repository and Packaging Costs

The final evaluation was preceded by deliberations among the experts, concerning the assignment of weight factors to the results of the six aforementioned criteria fields. Application of a "typical" set of weight factors, typical in that safety, fields I and V, always ranked highest, led to results as given by the left column of the pairs in Fig. 6, each pair representing a certain concept alternative. This suggests a ranking with BD1 and BD2 at the top, followed by D* and B. Due to the uncertainties of the underlying analyses and of the evaluation procedure itself only one result should be formulated at this point: Concept D, three-level drift emplacement without advanced ILW treatment, fails to qualify for further considerations.

According to the safeguard guidelines as established by the Federal Ministry of Research and Technology (BMFT), two pivotal points have to be observed. Reprocessing waste

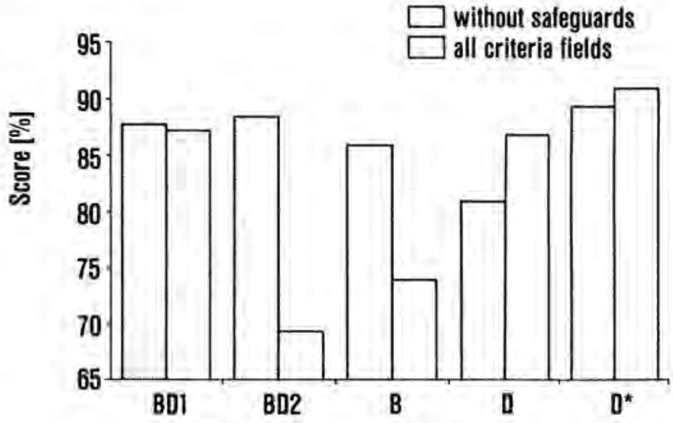


Fig. 6. Concept Evaluation

which is likely to meet the criterion for termination of safeguards prior to disposal has to be separated spatiallly in the repository from spent fuel for which such termination is not achievable. The second guideline to be observed is the access to spent fuel during repository operation. Spatial separation is achievable for all concepts except BD2; access to the waste, at least for some time, might be possible in the case of the drift emplacement concepts, is unlikely for BD1, and practically impossible for the pure borehole concepts. This suggests a score of 100% for the drift concepts, 80% for BD1, 30% for the borehole concept and only 10% for BD2.

If the safeguard results are weighted appropriately and combined with the results of the six previous criteria fields, an overall score as represented by the right columns of Fig. 6 is obtained. In spite of all uncertainties associated with the evaluation procedure, concept BD1 and the drift emplacement concept with advanced ILW treatment deserve to be subject to further analysis in the next years. By that choice the crucial points of future repository development are covered such a boreholes and drift emplacement technology, shaft transport, etc. It seems advisable to pursue concept B, the borehole concept, until all problems surrounding hoisting requirements for the POLLUX-cask are solved.

Besides this choice of promising concepts, the Systems Analysis Dual-Purpose Repository helped to detect areas with R&D deficiencies such as:

- Effects of high burn-up and MOX-fuel on the repository,
- In-depth thermomechanical analyses of multi-level drift emplacement,
- Consequences of a departure from the 200°C-near-field design basis and
- Consequences of hydrogen in the repository.

A new R&D program funded by BMFT, which is scheduled for the period 1990-92, will center on these issues.

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