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ADVANCED TECHNIQUES FOR STORAGE AND DISPOSAL OF SPENT FUEL FROM COMMERCIAL NUCLEAR POWER PLANTS

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Abstract

Electricity generation using fossil fuel at comparatively low costs forces nuclear energy to explore all economic potentials. The cost advantage of direct disposal of spent nuclear fuel compared to reprocessing gives reason enough to follow that path more and more. The present paper describes components and facilities for long-term storage as well as packaging strategies, developed and implemented under the responsibility of the German utilities operating nuclear power plants. A proposal is made to complement or even to replace the POLLUX cask concept by a system using BSK 3 fuel rod containers together with LB 21 storage casks.

1. INTRODUCTION

Competition among various techniques of electricity generation under liberalised market conditions forces utilities and the nuclear industry to strictly control their costs and to finish unsettled issues as far as possible. In order to ensure competitiveness in the field of spent fuel and radioactive waste management, all cost saving potentials at all steps along the route toward direct disposal have to be explored. At the same time the highest levels of safety standards as well as the flexibility for future improvements, decisions and regulatory needs have to be maintained. Concepts designed in the past decades, therefore, have to be reassessed and confronted with new developments and requirements in view of their commercial use.

2. THE ACTUAL SITUATION IN GERMANY

Twenty nuclear power plants with a capacity of about 23 GWe produce some 450 t (HM) of spent fuel per year on an average. An amendment of the German Atomic Act in 1994 was a precondition for the direct final disposal of spent fuel without prior reprocessing. At present, two away from reactor interim storage facilities have been commissioned, a pilot conditioning plant is close to completion and a repository for heat generating waste is under exploration. The cost advantage obtained by direct disposal, which meanwhile for some nuclear power plants is a precondition for economic operation, initiated further improvements. Hereby, experience which has been gained for several years in the field of dry interim storage of spent fuel assemblies, served as a basis. The main components and facilities are described below. For detailed information see [1,2].

3. TRANSPORT AND STORAGE CASKS FOR SPENT FUEL ASSEMBLIES

Before being sent to an underground repository spent fuel needs to be cooled down in long-term interim storage facilities. To minimise related costs, big-sized casks of the CASTOR® V-type have been developed, which in future will be mainly used. Casks of the CASTOR® family consist of a thick-walled cylindrical cask body and a double lid system. The cask body is made of ductile cast iron with nodular graphite (ductile cast iron GGG 40). The lids are made of stainless steel. All lids are screwed and leak-tightened with long-lasting metal seals. Radial fins at the outside of the cask body improve passive heat dissipation to the environment. For neutron shielding polyethylene bars are assembled in uniformly distributed drillings in the cask wall. In the bottom area as well as on the lower side of the secondary lid plates of the same material are incorporated. Two pairs of trunnions are screwed onto the cask body. The basket bearing the fuel assemblies is welded and consists of borated special steel plates. To minimise the impact load at the lid and bottom ends of the cask body in case of accidents during the transport, shock absorbers of energy absorbing wood with a steel liner are installed. The casks meet the IAEA safety regulations for type B(U)F-packages. Furthermore, they comply with the acceptance requirements of the interim storage facilities at Gorleben and Ahaus. So far, some 600 casks of different types have been manufactured (Table 1). For the purpose dealt with here mainly CASTOR® V–types will be considered.

TAB. 1. OVERVIEW: PRODUCTION AND USE OF CASTOR® CASKS

Cask Type	Contents	Produced	Loaded	Remarks
CASTOR Ia	4 PWR FAs	1	-	
CASTOR Ib	4 PWR FAs (short)	7	-	internal transports at KWO
CASTOR Ic	16 BWR FAs	11	1	1 TBL-G; 1 internal transports at KKP
CASTOR IIa	9 PWR FAs	1	1	1 TBL-G
CASTOR IIb	8 PWR FAs (short)	3	-	internal transports at GKN
CASTOR KRB-MOX	defective WWER FAs in special basket	4	-	KGR fuel for storage at ZLN
CASTOR THTR/AVR	THTR/AVR FAs	474	399	305 TBL-A; 94 FZJ
CASTOR 440/84	84 WWER-440 FAs	32	6	3 KGR + 3 KKR to be stored at ZLN
CASTOR V/19	19 PWR FAs	13	6	3 TBL-G; 3 TBL-A
CASTOR V/52	52 BWR FAs	3	3	3 TBL-A
CASTOR MTR 2	Research reactor FAs	1	-	VKTA fuel for storage at TBL-A
CASTOR HAW 20/28 CG	28 HAW-canisters	12	8	2 TBL-G; 6 at La Hague transports to TBL-G pending
TS 28 V	28 HAW-canisters	1	1	1 TBL-G

FZJ	Research Centre Jülich	KWO	NPP Obrigheim
GKN	NPP Neckarwestheim	TBL-A	Ahaus Interim Storage Facility
KGR	NPP Greifswald	TBL-G	Gorleben Interim Storage Facility
KKP	NPP Philippsburg	ZLN	Interim Storage Facility at Greifswald
KKR	NPP Rheinsberg		

3.1. CASTOR® V/19

The CASTOR® V/19 cask [3] is designed for transport and interim storage of spent fuel assemblies from 1300 MW type PWRs (Fig. 1). The capacity of the cask corresponds to 19 uranium fuel elements with a maximum average burnup of 55 GW·d/tHM and an initial U-235 enrichment of up to 4.05 (wt)% or 15 uranium fuel assemblies plus four special fuel assemblies, which could consist of MOX (with a maximum average burnup of 55 GW·d/tHM and a fissile material content (fissile Pu + U-235) up to 3.95 (wt)%, thereof a maximum of 3.7 (wt)% of fissile Pu) or uranium fuel assemblies with a maximum average burnup of 65 GW·d/tHM and an initial U-235 enrichment of up to 4.05 (wt)%.

3.2. CASTOR® V/52

The transport and storage cask CASTOR® V/52 is designed for a maximum of 52 fuel assemblies from German BWRs which can be disposed of together with their fuel channels. The dimensions of the CASTOR® V/52 take into account all designs of fuel assemblies that are currently being used in German BWRs and will be used in the future according to today's knowledge. The construction corresponds to that of the CASTOR® V/19. Among the 52 fuel assemblies, there may be up to 16 special fuel assemblies, e.g. containing high burnup Uranium or MOX respectively on specified basket positions. Payloads up to 32 fuel assemblies including up to 12 special fuel assemblies on specified basket positions together with twenty outer basket positions filled with steel dummies. With that additional shielding at the outer basket area a reduction of the minimum cooling time at the expense of the cask capacity can be achieved.

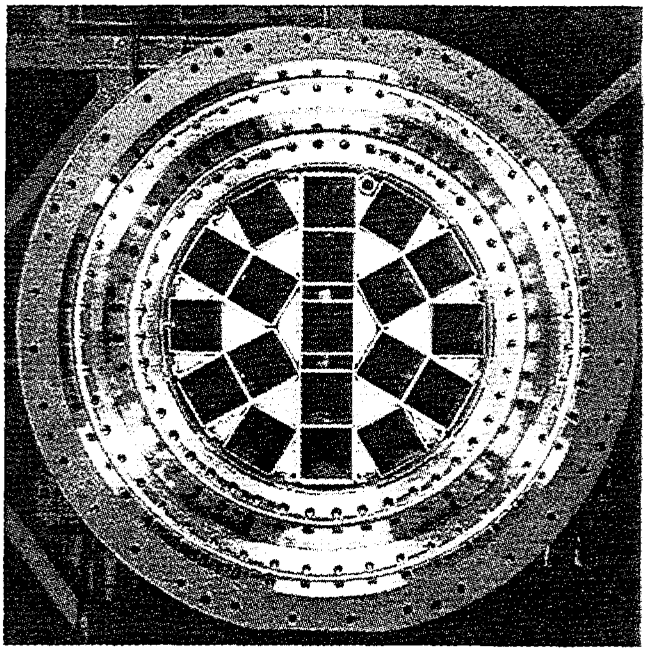

FIG. 1. CASTOR® V/19

3.3. Final disposal cask POLLUX

In the frame of R&D activities in the field of direct disposal of spent fuel a triple purpose cask for transport, storage and final disposal has been developed [4]. The POLLUX type cask (see Fig. 2) is designed to be disposed of in drifts of a salt dome repository. Precise and final design requirements, however, cannot be formulated before the exploration of the Gorleben salt dome is completed.

The safety analysis report and the licensing documents according to the regulations of the Atomic Act were submitted to the licensing authorities, Bundesanstalt für Materialforschung und -prüfung (BAM) and Bundesamt für Strahlenschutz (BfS) for obtaining the license according to the transport regulations, type B(U)F, and the storage license according to the acceptance requirements of the Gorleben interim store. A drop test programme was carried out in 1994 to demonstrate the cask safety under type B(U) conditions. All licenses for the POLLUX cask are expected to be issued in 1999.

The fuel assembly that formed the design basis is a standard PWR fuel assembly (which has also been used for the CASTOR® V/19 design). All design requirements which can be derived from the remaining PWR and BWR assemblies under consideration are covered by that type. The maximum load includes ten Uranium fuel assemblies or alternatively seven Uranium plus three MOX fuel assemblies with a fuel equivalent of about 5.5 tHM.

Fig. 3 shows the basic design of the POLLUX final disposal cask. It consists of the shielding cask with an inscrewed lid and an inner cask with bolted primary and welded secondary lid. The fuel rods to be stored is inserted in the final disposal cask in cans. The cylindrical wall and the bottom of the inner cask are extruded in one piece and made of fine grained steel. The body of the shielding cask also consists of one piece and is made of ductile graphite iron. Two rows of bore holes in the wall of the shielding cask are filled with moderator material. Besides its primary function, to keep the gamma and neutron doses rate at the surface below the licensed limits, the shielding cask also serves as overpack to meet disposal criteria.

Presently, a prototype cask undergoes cold handling testing in the Pilot Conditioning Facility (PKA, [5]) in Gorleben. Further development of the Pollux cask towards an universal system for transport, interim storage and final disposal could lead to a promising low cost multi-purpose cask concept in the future.

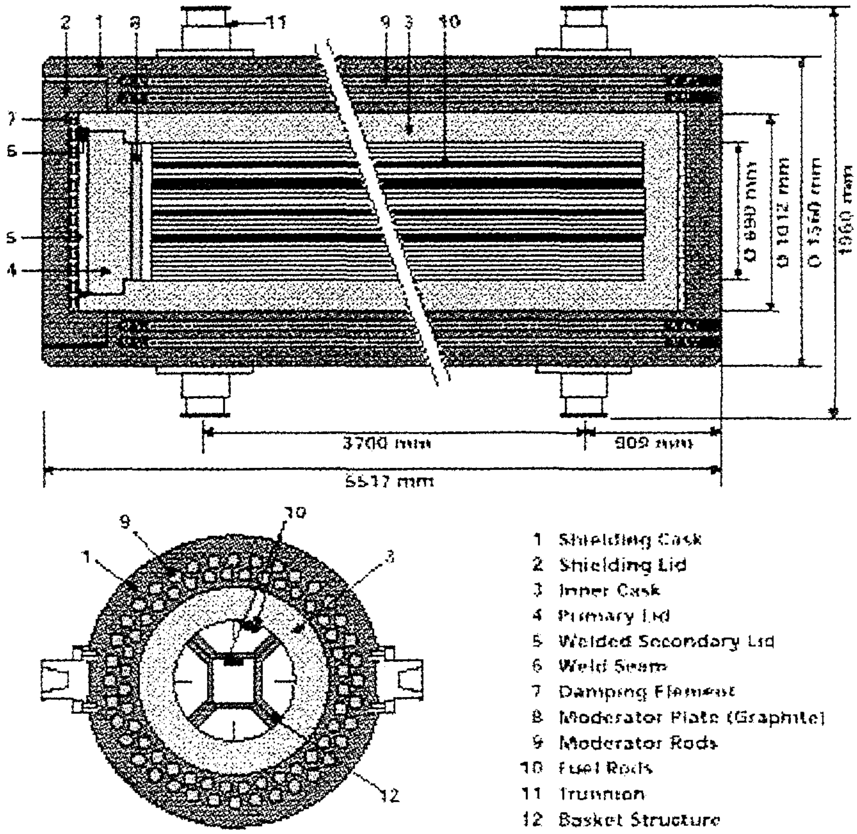

FIG .2. Final disposal cask POLLUX

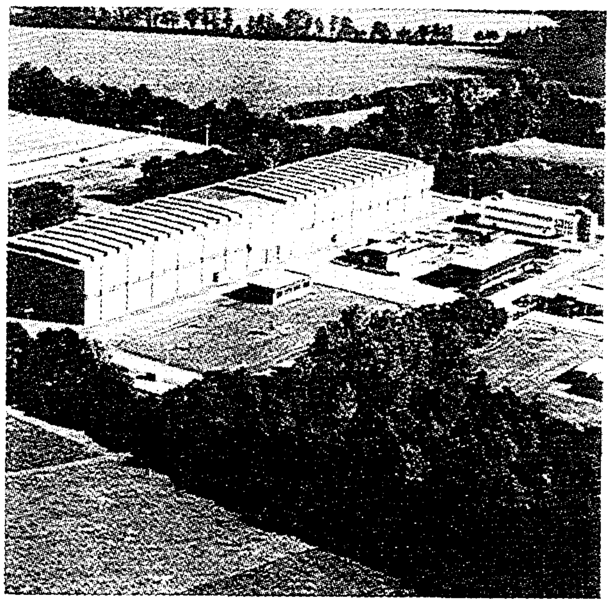

FIG. 3. Ahaus Interim Storage Facility

4. LONG-TERM INTERIM STORAGE OF SPENT FUEL

4.1. Ahaus Interim Storage Facility

The interim storage facility in Ahaus (Fig. 3) consists of a storage hall with the dimensions (l x w x h) 196 m x 38 m x 20 m. It is subdivided into a reception area in the center of the hall where casks are unloaded from the transport vehicles and prepared for storage, and two storage areas where casks are placed in upright position for interim storage. The dissipation of residual decay heat is effected by natural convection through openings in the roof.

From June 1982 to February 1995 305 CASTOR® casks with spent fuel of the decommissioned THTR were brought to the Ahaus facility. In 1998, further six casks of the CASTOR® V series with a total of about 55 tHM from light water reactors (BWRs) were added. The currently valid storage licence comprises a total of 3,960 tHM.

4.2. Gorleben Interim Storage Facility

The transport cask storage facility in Gorleben consists of a storage hall of the same construction and dimensions as the one in Ahaus with a capacity of 420 storage positions for CASTOR® LWR casks. The first license issued in September 1993, allowing the storage of 1,500 tHM LWR fuel, was extended in June 1995. Thus, it comprises now a total of 3,800 tHM and includes the storage of fuel assemblies with higher burnup in an extended cask spectrum as well as the storage of vitrified high level waste from reprocessing abroad. The facility was constructed between 1981 and 1983 and taken into hot operation on April 25, 1995 with the storage of a CASTOR® IIa loaded with 9 fuel assemblies of the nuclear power plant Philippsburg-2 (KKP-2). Later a TS 28 V and 2 CASTOR® HAW 20/28 CG casks each filled with 28 cans of vitrified HLW from reprocessing in France were added. Together with three further CASTOR® V casks with spent PWR fuel a total of 8 casks is currently stored.

4.3. Pilot Conditioning Facility Gorleben (PKA)

On behalf of the German utilities, GNS constructed a plant in Gorleben, which is supposed to demonstrate spent fuel handling and to test all general services for interim storage and final disposal of spent fuel and high level waste. The process building of the PKA has been completed and the installation of the technical equipment (e. g. hot cells) will be finished within 1998. The third partial licence (commissioning) is scheduled for 1999. Exemplary for the tasks of the PKA are all kinds of cask services, testing of reloading techniques of fuel assemblies from interim storage casks into final disposal casks including fuel rod consolidation [5,6].

5. SPENT FUEL DISPOSAL STRATEGIES

5.1. Reference concept

The "classic" German way of spent fuel disposal is shown in Fig. 4 (left part). The illustrated concept served as a basis for the development and planning of the described techniques, components and plants.

After a minimum cooling period of 5 years, fuel assemblies from German LWR are loaded into casks of the type CASTOR® V in the storage ponds of the power plants and transported to one of the away-from-reactor interim storage facilities in either Ahaus or Gorleben. Since CASTOR® casks comply with the transport requirements as well as with the acceptance requirements of the storage facilities for long-term interim storage, a reloading is not necessary. After the respective storage period needed for spent fuel cooling and under the precondition that a suitable final disposal facility is available, the casks are transported to the conditioning plant. Here, the fuel assemblies are unloaded, disassembled and packed into containers suitable for final disposal. Therefore, the fuel rods of 10

PWR-assemblies (or an equivalent of BWR-fuel) are loaded into 5 so called POLLUX-cans. The latter again are loaded into a POLLUX cask (Fig. 3). The remaining skeletons of the fuel assemblies, from which the fuel rods have been removed, will be compacted and space-sparingly disposed of, e.g. using MOSAIK casks. It is presumed that the CASTOR® V, used for transport and long-term interim storage, is scrapped.

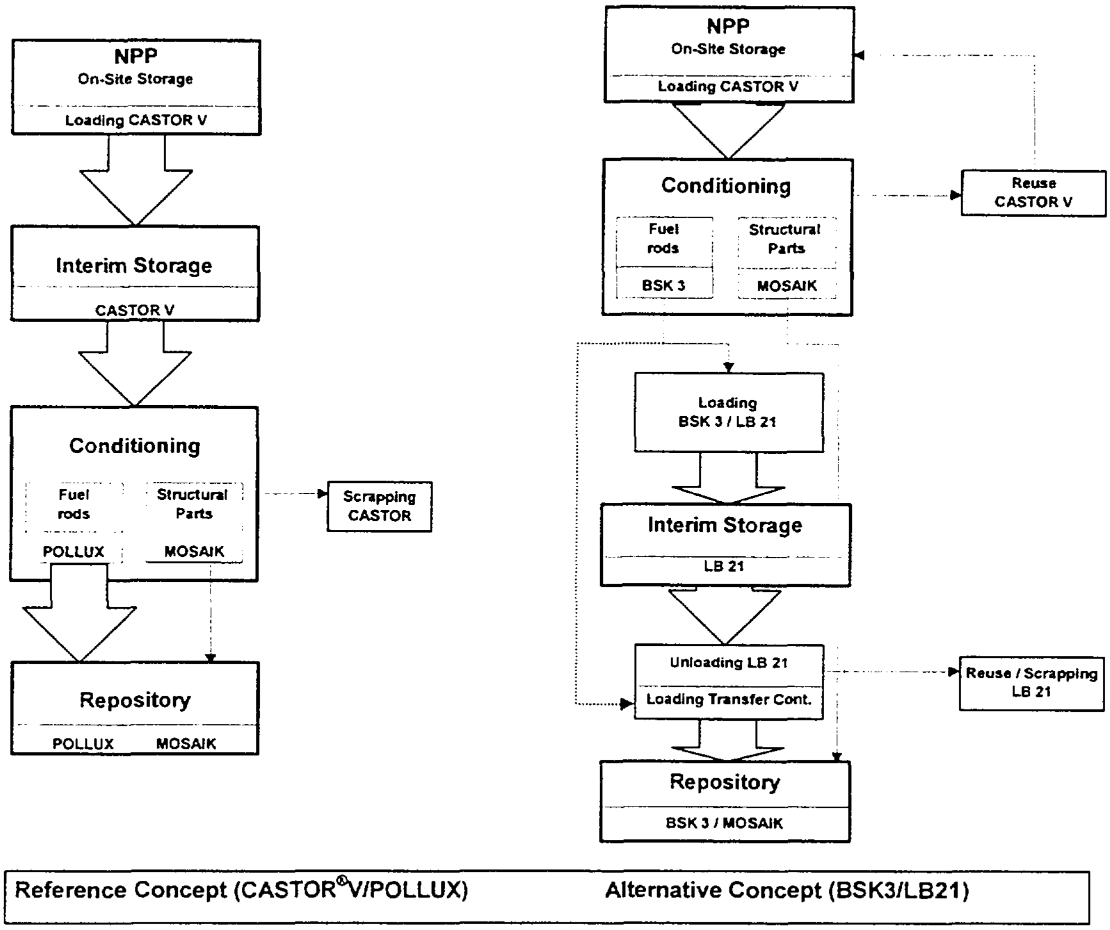

Fig. 4. Disposal strategies

5.2. The alternative concept

A simple break-down of costs for the entire route of disposal divided into costs for transports, casks, interim storage and conditioning (Fig. 5) prior to repository emplacement shows that those casks used for interim storage and final disposal represent most of the total costs. Investments already made for the existing interim stores, the conditioning facility as well as the repository costs, which are inevitable and independent from the route of disposal chosen, have not been taken into account. These considerations, though, only apply for the actual situation in the Federal Republic of Germany and, therefore, are not transferable to other countries.

Bearing in mind the aforementioned need of reducing spent fuel and waste management costs, an alternative approach is now being considered (Fig. 4, right part). Consequently, it puts emphasis on the avoidance of expensive interim storage and final disposal casks. The essential item is the packaging of fuel rods into a final disposal fuel rod canister, which, in contrast to the POLLUX cask, is not finally disposed of in repository drifts but in bore holes. Therefore, heavy shielding is not necessary. These final disposal fuel rod canisters can be tightly sealed using a qualified welding process in the conditioning facility. This allows interim storage, which is necessary until a repository becomes available, in casks of a simplified design without the otherwise necessary double lid system. Those fuel assemblies foreseen for final disposal are loaded into transport casks in the reactor after the respective cooling period and transported to the conditioning facility where they are unloaded. In contrast to the reference concept, the fuel rod container named BSK 3 (see Fig. 6) forms the final disposal container [6]. It contains the consolidated fuel rods of 3 PWR fuel assemblies (or of 9 BWR fuel assemblies). Seven BSK 3 containers are loaded into a storage cask of the type LB 21 (Fig. 7), which is bridging over the period until the availability of an underground repository. For emplacement of the BSK3 containers into repository bore holes the LB 21 is brought back to the conditioning facility. The containers are unloaded and transported inside a shuttle cask either individually or in groups to the underground facilities. The fuel rod skeletons are compacted in the same way as mentioned in the reference procedure, loaded into MOSAIK casks and finally disposed of.

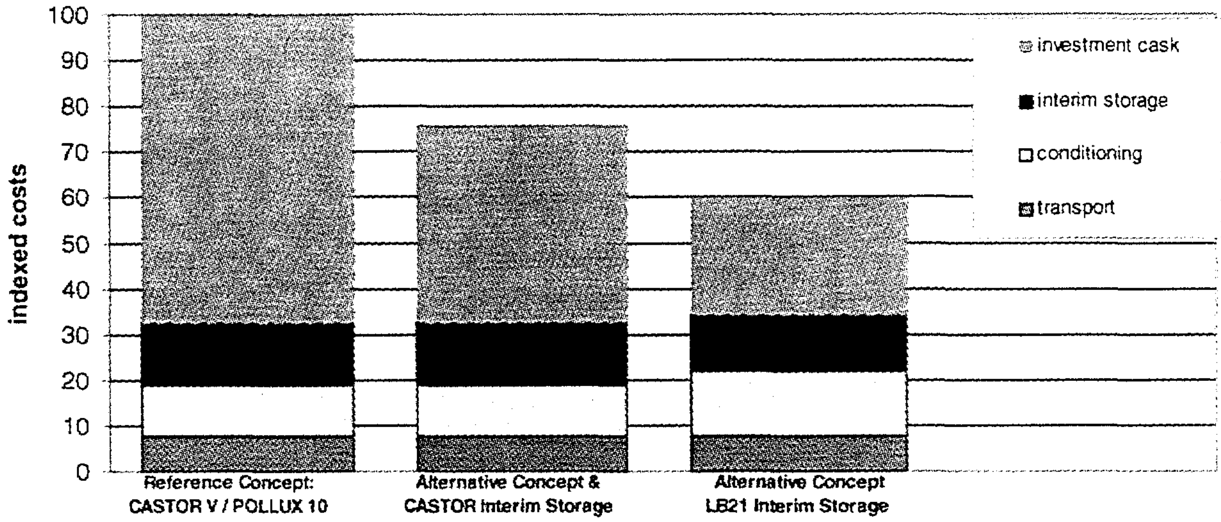

Fig. 5. Cost comparison of different disposal strategies

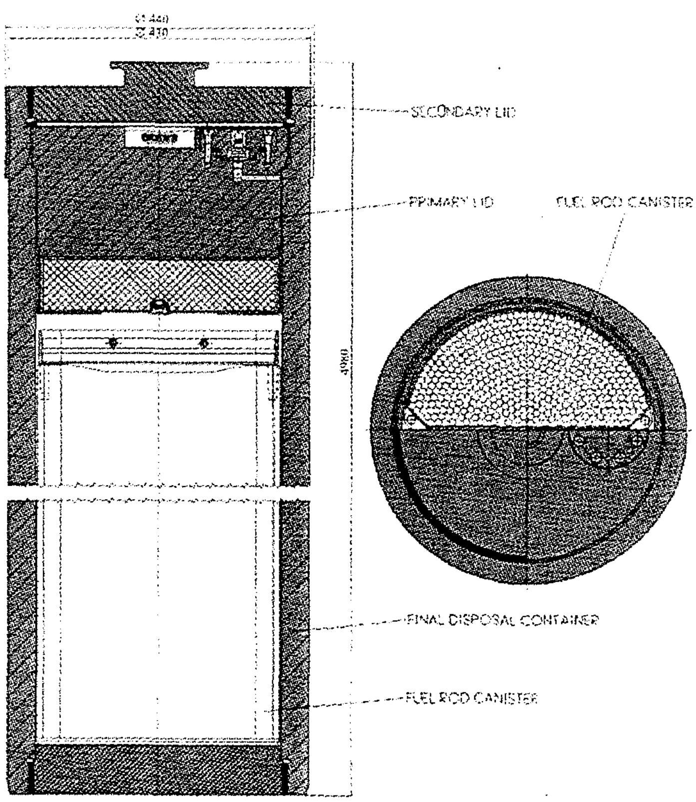

FIG. 6. Fuel rod canister BSK3

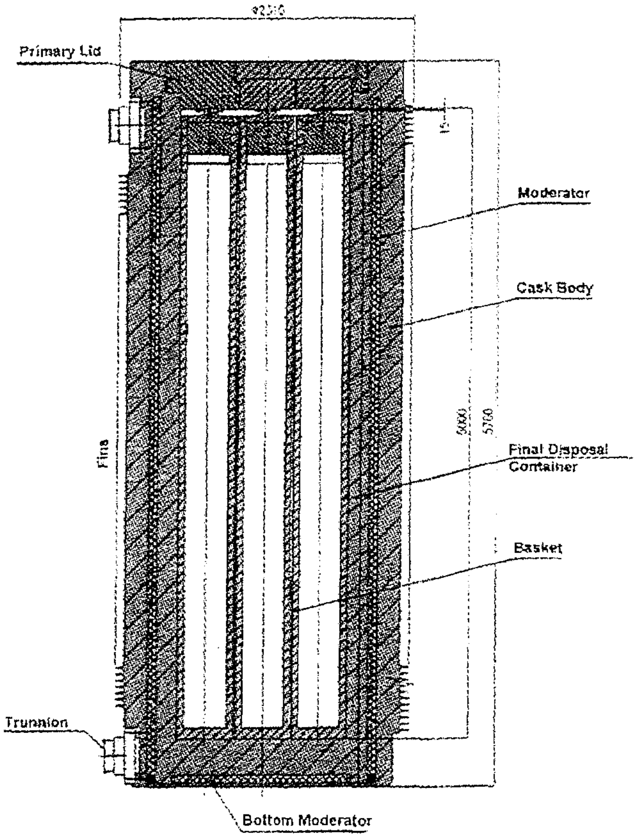

FIG. 7. Storage cask LB21

Apart from cost saving aspects, the alternative concept offers extensive flexibility. Positive aspects are:

- the comparatively expensive CASTOR® V cask is exclusively used for the transportation to the interim store, respectively to the conditioning facility. A multiple use of the cask leads to a higher cost efficiency;

- the diameter of the BSK 3 fuel rod canister corresponds to the diameter of vitrified high level waste cans already produced in high numbers and also destined for final disposal. This allows a standardized handling for HLW and spent fuel, also at the final disposal site;

- the BSK 3 fuel rod canister is tightly closed using a qualified welding process in the conditioning facility. Therefore, the interim storage cask LB 21 does not need the usual double lid system;

- the inventory of one LB 21 cask filled with 7 BSK 3 fuel rod canisters correspond to a capacity of 21 PWR-fuel assemblies. The utilisation of storage positions in the interim storage facility and thus the specific storage costs are reduced accordingly in comparison with a CASTOR® V with a capacity of 19 PWR assemblies.

According to the numbers shown in fig.4 the disposal costs of the presented alternative concept decrease to approximately 60 % of the reference concept. Of course, every intermediate solution taking into account short or medium-term interim storage of spent fuel in CASTOR® V casks is conceivable. The cost will then depend on the interim storage period. But they are in any case lower than those of the reference concept.

The transition from the reference concept to the alternative concept requires only minor modifications of the technical equipment of the conditioning plant. The design of the LB 21 storage cask is based on the CASTOR® HAW 20/28 CG for HLW-cans from reprocessing, which is already in use (see Tab. I). The demonstration of the described techniques will be included in the PKA commissioning programme.

Further, significant cost reductions are possible due to the flexibility of the proposed approach with respect to time:

- taking into account the favourable thermal conditions of the BSK 3 fuel rod canisters compared with the POLLUX cask emplacement in salt rock bore holes can be carried out much earlier (about 7 years after unloading instead of 20-30 years).

Upon availability of a repository site the entire period of interim storage following the conditioning process, including the use of the LB 21, can considerably be reduced or even be dropped. This could eventually reduce costs down to less than 30 % of the reference concept.

6. FUTURE IMPROVEMENTS

The development of advanced cask designs aims at increased spent fuel inventories together with higher burnup or a higher initial U235 enrichment. In addition, a growing amount of spent MOX fuel originating from the recycling of reprocessed Plutonium needs to be taken into account. Weights and dimensions of spent fuel casks reached already the limits set by the technical boundary conditions of power plants. Therefore, intelligent solutions are required. Among them, an optimized moderator configuration, compact basket designs, new materials and new fabrication processes need to be considered. Table II compares data of the actual CASTOR® V/19-design with an advanced type presently under development.

TABLE II. PROGRESSIVE CASK CONCEPTS

	CASTOR V/19	**CASTOR Va**
Capacity (PWR FAs)	19	21
Max. Number of MOX-FAs	4	8
Max. Enrichment [%]	4,45	5,0
Burnup [GW·d/tHM]	maximum 55 (15 FAs) maximum 65 (4 FAs)	average 65 maximum 75
Typical cooling time [month]	60	60

Licensing procedures which in general represent extensive and time consuming activities should also be subject to revision. At present, licences for casks together with their contents form part of the storage licence of the respective storage facility according to the German Atomic Act. For the future it is proposed to separate the cask licences from those of the storage facilities. The latter should then form an "umbrella licence" comprising all requirements which all individual casks have to comply with. Thus, when new cask designs or minor technical revisions are desired extensive reviews of storage licences can be avoided.

7. CLOSING REMARKS

Continuous improvements aiming at higher effectiveness and efficiency are common procedures in all industrial areas. Here, nuclear energy is no exception either. However, problems cause the long time periods needed to achieve changes or modifications that are either desired or required. In order to allow adaptations to changing situations in due time, future developments have to be considered and initiated well in advance. Redundancy and diversity are typical key words of the nuclear technology vocabulary. These terms usually used in the hardware sector of safety technology also apply to the spent fuel management strategies in order to ensure the economic operation of the German nuclear power plants. In Germany the technology of direct final disposal, as a complementary measure or as an alternative to reprocessing, is available. The paper presented here shows that the necessary casks and systems together with the typical facilities for long-term storage and conditioning already exist. The facilities are in operation or in progress of commissioning. However, the alternative concepts discussed here need to be developed in more detail. A prerequisite for the realisation, i.e. the necessary political support, has not been investigated here. It is especially this area where Germany currently has to face a difficult situation.

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