RESULTS OF ENGINEERING DEVELOPMENTS FOR THE DIRECT DISPOSAL OF SPENT FUEL

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ABSTRACT

Within the scope of the project "Alternative Disposal Techniques", sponsored by the Federal Ministry for Research and Technology (BMFT) and the Deutsche Gesellschaft für Wiederaufarbeitung von Kernbrennstoffen mbH (DWK), NUKEM and DWK developed final disposal casks for the direct final disposal of spent fuel elements and a basic design of a corresponding conditioning plant. The research and development activities were carried out during the period from 1981 through 1984.

The main features of the casks presented are the multishell structure. The following final disposal cask options were selected for development:

- final disposal cask made of steel with an anti-corrosive layer consisting of:
  - o Hastelloy C4 cladding
  - o Hastelloy C4 resurfacing by welding
  - o Hastelloy C4 resurfacing by welding and glass ceramic
- final disposal cask made by composite casting with electrochemical protection.

BACKGROUND

Nukem and DWK were concerned with the development of final disposal casks and encapsulation techniques. These results would be needed for the comparitive assessment study between fuel reprocessing and direct final disposal carried out by Karlsruhe Nuclear Research Center.

DESIGN CRITERIA

Nuclear data

- Reference fuel element	Biblis
- Burn-up	40,000 MWd/TU O_2
- Core residence time	1,000 d
- Initial enrichment	3,6 % U-235
- Decay period until conditioning and final storage	10 a
- Throughput of the conditioning	700 TU O_2/y

Specific repository data

- Host rock for final storage	salt
- Initial rock temperature	about 44° C
- Reference disposal configuration	in horizontal galleries
- Time of operation of repository mine	50 a
- Number of different salt brines under investigation	8
- Composition of quinary brine at 100° C	26,5 W % Mg C/2 4,7 W % Kcl 1,5 W % Mg SO_4 1,8 W % Na Cl
- Temperature of hottest fuel fod	max. 300° C
- Surface temperature of waste package in repositiory	max. 150° C

Radiation shielding data (final disposal cask)

- Max. admissible surface radiation (during shipment and intermediate storage)	0,1 m Sv/h at 1 m distance

CORROSION TESTING

The main characteristic of the concepts chosen for the final disposal casks is a multilayer construction with independent technical barriers and containment. An important aspect of each introduced concept is manufacturing and quality assurance of the corrosion-resistant-layer. It must withstand a brine due to a postulated flooding of the repository over a period of 500 years, although geological experience and appropriate technical steps in mining operation and backfilling make such an event highly unlikely.

Testing of titanium base alloys

The investigations concerning the corrosion behavior of candidate materials were carried out in 2 steps. In project stage 1, different materials such as

- Mild steels
- Stainless steels
- Nickel base alloys
- Copper base alloys
- Ceramics
- Graphite-nickel sulfide composites

were tested for their usability in testsolutions at the temperatures 100, 150 and 200^{o} C. The criteria for use as corrosion-resist- antlayer material for final disposal casks were acceptabe uniform corrosion rates and exclusion of local corrosion effects, which would lead to quick destruction of the package or to loss of mechanical integrity of the package.

In the course of the tests, it was decided to give up the palladiumalloyed material in order to preserve the Pd-resources.

After 6 months in solution, titanium grade 2 showed crevice corrosion under a deposit and was, therefore, taken out of the test.

With TiCode 12, many specimens were tested. One cupped specimen showed a crack, which originated from a notch and extended far into the interior. The overall findings contrast with the foregoing failure, which is totally unexpected in view of the results of extensive studies by other authors. As a conclusion of the postexaminations of the failed specimens, it appears to be most likely that the defect cannot be blamed on SCC. Owing to this reevaluation, TiCode 12 also was added to the investigations of phase 2.Here, the corrosion rates were obtained, being in the order of magnitude of several hundredths of one µm/a for 100 or 150 ^{o} C, and thus, the suitability of this material under these conditions was verified.

Testing of Nickel Base Alloys

In project stage 1, several materials form the group of nickel base alloys were also employed in the screening tests to evaluate their suitability. The tested alloys were

- Monel 400
- Hastelloy C 4
- Inconel 600
- Inconel 625
- Inconel 750 x
- Incoloy 825

Only Hastelloy C4 from this group succeeded in entering project stage 2. The others exhibited local corrosion effects.

In all cases, 5 parallel samples were used in order to be able to make a stastical analysis including standard deviation of the corrosion rate. Recommendations by the German standards (DIN) were obeyed, e.g., with regard to specimen surface, volume of corrosion agent and analysis of the results obtained. The mean linear corrosion rate is lower than one µm/a for 100 or 150^{o}C. As it is well known, welding seams and heat-affected zones are often trouble areas of corrosion. Therefore, the possible types of welding seams were tested too.

One container variant, considers applying Hastelloy C4, which provides the corrosion protection, by way of built-up welding onto a suitable base structure made of steel. Thereby, the first layer directly adjacent to the base structure will not generally attain the composition of Hastelloy C4, which is necessary to guarantee corrosion protection. For this reason, multilayer welding is indispensible. Analytical examinations reveal that the composition of Hastelloy C4 can be guaranteed if the layer is sufficiently thick. The suitability of Hastelloy C4 under these conditions was also verified.

Testing of Iron Base Alloys

The corrosion testing of iron base alloys comprises 3 different groups of materials

- Stainless steels
- Lamellar and nodular cast iron
- Nodular austenitic cast iron

as well as a special type of container with cathodic corrosion protection.

Investigations with stainless steels

Specimens made of ferritic and austenitic stainless and acid-proof steel were included in the comprehensive testing of project stage 1 in order to be able to assess the behavior of this material, too. As was expected, all of these alloys suffered relatively soon from local corrosion.

Investigations with cast iron

Exposures of gray cast iron with lamellar graphite soon revealed the danger of graphitic corrosion, i.e., selective dissolution of iron with the preservation of the graphite matrix. So no more testing was carried out.

Cast iron with nodular graphite is not endangered by graphitic corrosion, because the graphite spheres are removed along with the dissolution of iron during corrosion. The findings of our tests show a strong impact of termperature. For 95 to 100 ^{o} C, the corrosion rates in various solutions ranged from 5 to 25 µm/a and for 150^{o} C from 150 to 250 µm/a.

Investigations with austenitic cast iron (Ni-Resist D2)

Austenitic cast iron with 20 % Ni and 1,2 % Cr displays superior corrosion properties over ferritic cast iron. Surprisingly, stress corrosion cracks were discovered during a routine check for SCC susceptibility by way of Brinell ball indentations, a fact, which was verified with further samples. Due to these findings, this material was no longer tested at that time.

Investigations with regard to the concept of a canister with cathodic corrosion protection

One canister consisting of successive materials, which become more noble towards the inner side was discussed. According to this, a tube of stainless steel is immersed into molten GGG 40.3 at a defined temperature where they cool together. According to the concept, corrosion will start uniformly at the outer cast iron package in case of an accident. This package is sufficiently designed not to be used up in a projected term of 500 years. If, nonetheless, the cast iron jacket should rupture because of corrosion or mechanical damage, a short-circuit cell will form, with the cast iron jacket being the anode and the stainless steel acting as the cathode.

Laboratory tests running for more than a year, have shown that the stainless steel is polarized cathodically very strongly by the cast iron so that no local corrosion can occur. The suitability of this dual layer castings was verified.

FINAL DISPOSAL CASKS

The main characteristic of the concepts chosen for these casks is a multilayer construction with independent technical barriers and containment. The multibarrier system ensures a direct final disposal of spent fuel elements in a salt dome repository, gas-tight for a period of 50 years and leakproof for 500 years.

The constructional concept of the final disposal cask is modular. Fig. 1, from the inside to the outside it consists of

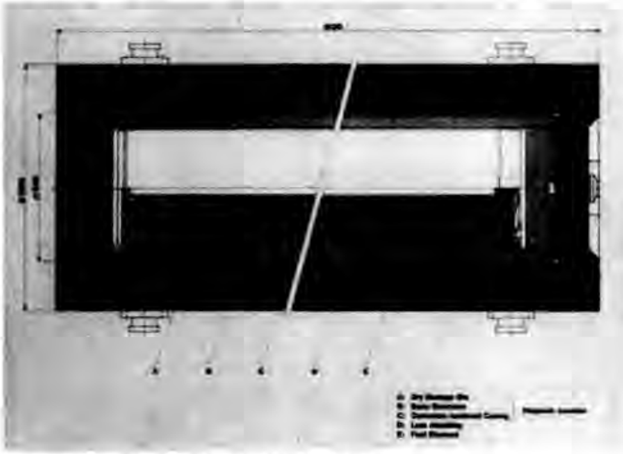

Fig. 1. Final Disposal Package.

- the dry storage bin containing 3 spent fuel elements, is sealed by a gas-tight welding seam
- the cylindrical steel or ductile iron final disposal cask, which contains the dry storage bin. The final disposal cask must resist the rock salt pressure and the protective coating on the surface must withstand corrosion in brine over a period of 500 years
- the non-returnable outside shielding which encloses the loaded and sealed final disposal cask and which reduces the radiation dose rate for safe handling and transport. In one of the concepts the radiation shielding is already integrated in the final disposal cask body.

An important characteristic of each introduced concept is manufacturing and quality assurance of the corrosion-resistant layer. It must withstand a brine over a period of 500 years, although geological experience and appropriate technical steps in mining operation and backfilling make such circumstances highly unlikely.

According to the corrosion resistance principle the following various conceptsof a final disposal cask were developed:

- final disposal steel cask with a corrosion-resistant layer of
  - o Hastelloy C4 - Overpack
  - o Hastelloy C4 - Build-up welding
  - o Hastelloy C4 - Build-up welding combined with ceramic material
- Final disposal dual layer castings with the electrochemical protection principle.

Apart from the corrosion resistance, other safety aspects were considered too, as they might be relevant in the licensing of the final disposal cask system. These aspects include

- gas-tightness and leakage rates
- design in respect of mechanical loads in normal and in faulty operational conditions
- heat transfer characteristics during transport and final storage
- radiation shielding
- criticality
- quality assurance.

It is demonstrated that these design criteria are well met by the described consepts.

Prototypes were manufactured of a dry storage bin, final disposal casks and non-returnable radiation shielding. Table 1 gives an overview of the characteristical data.

TABLE 1

Characteristical Data of Final Disposal Casks

(Suitable for 3 Uncut Fuel Elements)

CORROSION-PROTECTION		HASTELLOY-OVERPACK	BUILD-UP WELDING FOR HASTELLOY	ELECTRO-CHEMICAL PROTECTION
DRY STORAGE BIN				
Weight	ton	1,9	1,9	1,9
FINAL DISPOSAL CASK				
Length/Diameter	mm	5425/840	5690/1000	5900/1350
Weight incl. Lost Shielding	ton	11,5	19,5	45,7
Thickness-Cask body	mm	80	150	337 incl. Lost Shielding
Thickness-Corrosion Layer	mm	4	3	
LOST SHIELDING				
Length/Diameter	mm	5820/1420	6070/1400	
Weight	ton	37,2	28,1	
Thickness	mm	247	160	
WASTE PACKAGE				
TotalWeight (incl. 3 Fuel Elements, 2,6 ton)	ton	52,9	52,1	47,6

Characterization of Final Disposal Cask With Hastelloy-C4-Overpack

CASK BODY
- Forged Steel 20 Mn Mo Ni 55
  Therefore small wall thickness possible
- Integrated Bottom

PROTECTION AGAINST CORROSION
- Hastelloy-C4-Overpack

CLOSURE OF DISPOSAL CASK
- Lid Screwed on cask body
- Hastelloy overpack sealed by welding

Characterization of Final Disposal Cask With Build-up Welding Technique of Hastelloy-C4 for Corrosion Protection

CASK BODY
- St 35.8
  ductile and easily weldable steel

PROTECTION AGAINST CORROSION
- Building-up welding technique with hastelloy-C4
- Alternative: Building-up welding with hastelloy-C4 combined with ceramic material

CLOSURE OF DISPOSAL CASK
- Lid welded together with cask body (narrow gap weld)
- Seam is coated with a hastelloy-C4 weld

Characterization of a Final Disposal Cask With Electrochemical Corrosion Protection

CASK BODY
- Ductile cast iron

PROTECTION AGAINST CORROSION
- Electrochemical protection by a combination of stainless steel and ductile cast iron

The outer ductile cast iron body serves as a radiation protection shielding (Lost shielding)

CLOSURE OF DISPOSAL CASK
- Lid screwed into cask body
- Stainless steel cap welded onto stainless steel pipe
- Lid screwed on outer body

CONDITIONING PLANT

NUKEM/DWK have studied three conditioning processes from engineering viewpoints, although with differing depths of planning.

As reference process, the packing of three uncut fuel elements was planned to the extent that, on the basis of available technical documentation and the fundamental processing techniques tested, the initiation of a licensing procedure is possible.

For the second process to pack consolidated fuel rods as well, which leads to a greatly improved utilization of the packing volume, largely tested processing techniques were selected, although the planning was carried out in lesser detail.

In the first two processes, the fuel elements or fuel rods are sealed in packages finally stored horizontally in the disposal tunnel; the dimensions of these packages are determined essentially by the length of the objects stored, the physical conditions such as heat removal from the final disposal package, and criticality safety, as well as by the technical transportation possibilities underground. This leads to the package sizes discussed before.

In the third process, the so-called canister concept, the objective for the conditioning consisted of preconditioning the fuel, for instance by cutting the fuel rods, to the extent that it can be enclosed in a package which has the external dimensions of the canisters used for the storage of the vitrified, highly radioactive waste coming from the reprocessing system. The intent behind this objective is to store "Glass block canisters" and "FE canisters" in vertical bore holes in a so-called mixed concept.

This latter concept was studied in the same depth as the second process.

In the statements which follow, only the reference concept will be presented.

Corresponding to the reference process selected, the fuel elements, which have been in intermediate storage for 10 years, are delivered to the conditioning plant in transport casks, unloaded in the FE temporary storehouse, identified, and groups of three uncut fuel elements each are welded into dry storage bins which ensure the gas-thight sealing of the fuel for the 50 years during which the final disposal facility is loaded.

When filled and welded closed, the dry storage package is inspected and in the final conditioning station, is sealed into a final disposal cask. After inspection, the final disposal package produced can be handled directly.

The final disposal package is finally placed in a Typ B(U) licensed transport cask and in this form leaves the conditioning plant by rail for the final disposal repository.

Description of the Conditioning Plant

The conditioning plant is divided essentially into the following building components:

- A processing building
- Two rail transloading halls (incoming and outgoing transport casks)
- A transport cask temporary storehouse (incoming storehouse)
- Two halls for the inward transfer of the canisters and casks
- A service and social wing