The German Cask Concept for Interim and Final Storage of Spent Fuel: The Current Status of Development and Testing

H. Spilker, R. Hüggenberg, U. Knopp
GNB Gesellschaft für Nuklear-Behälter mbH

INTRODUCTION

For the direct disposal of spent-fuel elements, development work has been done since 1979 based on a governmental resolution. In the period 1981 - 1984 the R&D program "Alternative Disposal Technologies," sponsored by the Ministry of Research and Technology (BMFT), was established to study the technical feasibility and safety, as well as to demonstrate that direct disposal can be an alternative to reprocessing.

From 1985, the German nuclear industry continued to develop a final disposal cask and planned a pilot conditioning plant (PKA) for spent fuel.
As a result of this work, two containers have been developed:

- the final disposal cask POLLUX
  (for final storage in drifts),
- the final disposal canister
  (for final storage in bore holes).

These containers and the status of their development are described in more detail in this report.

DESIGN REQUIREMENTS FOR THE FINAL DISPOSAL CASK POLLUX

The following requirements have to be met by a final disposal cask:

- Safe enclosure of the radioactive substances
  - o after treatment in the pilot conditioning plant, during handling, transport and interim storage;
  - o during the operating phase of the final repository;
  - o after close down and sealing of the final repository.
- Appropriate shielding
  - o during handling above ground and
  - o during handling in the final repository.
- Transport and handling ability

- Suitability for final storage
    - o in drifts (reference procedure) and
    - o in bore holes.

These requirements, the properties of the handled fuel, and the specific data of the final repository led to the following planning conditions:

- barrier resistance in accordance with the requirements of a final repository	≥ 500 a
- temperature in the final repository	200 °C
- maximum rock (salt) pressure	300 bar
- maximum mass of cask	65 t

- type B(U) requirements in accordance with IAEA transport regulations
- approval for storage of radioactive substances in an interim storage facility.

DESIGN CONDITIONS - FINAL DISPOSAL CASK

A standard PWR fuel element was used as the design fuel element. Ten PWR fuel elements with a fuel equivalent of approximately 5.5 tHM were taken as maximum load for the final disposal cask. It was considered that the PWR fuel element could contain uranium or two types of MOX fuel, respectively. In accordance with the practiced mixed loading of nuclear reactors with approximately 2/3 uranium fuel elements and 1/3 MOX fuel elements, the same load variants were considered for the final disposal cask as an envelope.

DESIGN CONDITIONS - FINAL DISPOSAL CANISTER

The final disposal canister is designed to be loaded with fuel rods from 3 PWR or, alternatively, 9 BWR fuel assemblies. The outer diameter of the final disposal canister is the same as for the glass canister for vitrified high-level wastes from fuel reprocessing. Thus, a joint handling and final disposal of both canister types in bore-holes are possible.

STRUCTURE OF THE FINAL DISPOSAL CASK

Figure 1 shows the basic structure of the final disposal cask design. The cask consists of a shielding cask with screwed on lid and an inner cask with a screw-fitted primary lid and a welded secondary lid. The radioactive material is enclosed in canisters, the canisters themselves are loaded into the final disposal cask. Figure 2 shows the design of the final disposal cask in more detail.

INNER CASK

The cylindrical shell and bottom of the inner cask shown in Figure 3 are made of fine-grained construction steel 15 MnNi 6.3 pressed from one piece without seams. The wall thickness of the cylindrical shell is designed to comply with the mechanical and shielding requirements and is approximately 160 mm. The weight of the complete inner cask is approximately 21 tonnes.

Primary lid

The primary lid of the inner cask is made of the same materials as the inner cask. It provides for leaktightness and shielding before and during welding of the secondary lid.
Below the lid a plate is attached that is made of materials that moderate and absorb neutrons.

Secondary lid

The secondary lid of the inner cask is also made of the same material as the inner cask. It is welded to the cask body. The welded seam joint, which is approximately 50 mm thick, is made using a special technique - the narrow-gap welding (see Figure 4). It ensures leakproof and durable barriers against radioactivity releases during transport, storage, and final disposal of the fuel elements.

Inner structures

The basket structure of the inner cask consists of an inner square box that has sheets at each corner as space dividers, which simultaneously center the basket structure and ensure good heat transfer from the center of the cask. The central square position can be filled with the fuel rods of two PWR fuel elements or with compressed structural parts. Correspondingly shaped fuel rod canisters with consolidated fuel rods from two PWR fuel elements are inserted in the four outer segmented areas.

After remote-controlled loading, the canisters and the central basket position are sealed dust tight with lids.

To guarantee subcriticality after hypothetical flooding of the POLLUX cask, borated steel plates are screwed to the outside on three sides on the plane walls of the canisters. This measure ensures neutron decoupling between the canisters.

CORROSION PROTECTION

The complete inner cask can be covered with a corrosion protection coating to avoid corrosion, if the final disposal conditions should require it.

SHIELDING CASK

The body of the shielding cask is cast in a single piece from nodular cast iron GGG 40. It is designed to comply with the mechanical and shielding requirements and has a wall thickness of 265 mm. The weight of the body is approximately 34 tonnes.

There are two rows of drilled holes with moderating material arranged in the wall of the shielding cask.

Each one has 36 holes with a diameter of 75 mm each. The primary function of the shielding cask is to reduce the gamma and neutron dose rate at the surface, so as to comply with the envisaged limit for interim storage of 0.5 mSv/h. Furthermore, in the final repository, the shielding cask has to withstand the isostatic salt pressure of approximately 300 bar.
The shielding cask lid is screwed down using multiple-threaded trapezoidal threads.

CONSTRUCTION OF THE FINAL DISPOSAL CANISTER

The final disposal canister is a cylindrical cask. Its design and components are shown in Figure 5. It consists of:

- a cylindrical canister piece made of fine-grained construction steel;
- a welded lid plate with a grapple device, and
- two holes for the loading and ventilation.

The holes are closed by a primary plug and ventilation valve after loading. By welding the disposal canister after loading, the gas-tight containment of the radioactive material during transport, storage, and final disposal is ensured.

An anti-corrosion coating of the canister offers further protection against corrosion inside the repository. The loading of the final disposal canister with fuel pins from spent LWR-assemblies will be done in the PKA using hot cell technology. After completion, the canisters are inserted into a transport/storage cask (Figure 6).

RESULTS OF THE DESIGN CALCULATIONS
CALCULATED DOSE RATES

Based on the shielding geometry and burnup calculations using the computer code OREST, shielding calculations were performed for different types of fuel under consideration with a mean burnup of 55 GWd/tHM. The calculated dose rates at the cask surface are in compliance with the envisaged value for interim storage of 0.5 mSv/h.

CRITICALITY CALCULATIONS

The final disposal cask is designed in such a way that even during unfavourable operating events and assumed accidents, the neutron multiplication factor k_{eff} maintains below 0.95.
The criticality calculations show that the subcriticality of the loading arrangements is guaranteed by design, also in the case of assuming fresh fuel and assuming penetration of moderating water without salt content.

THERMAL CALCULATIONS

The maximum permissible thermal output during interim storage and in the final repository under normal conditions is derived from the following requirements:

- the integrity of the fuel cladding must be preserved, and
- the integrity of the cask and the enclosure of the radioactive materials must be guaranteed for the long-term storage.

In addition it could be shown, that the surface temperature of the cask was below 85 °C as demanded by transport regulation for a type B(U) package.

MECHANICAL DESIGN

Stress Analysis for 9-Metre Drop Test

The verification that the final disposal cask withstands the load conditions to be taken into account in its design is provided by FEM calculations and drop tests with a 1:1 prototype cask.

The final disposal cask is initially designed to withstand the rock salt pressure under final disposal conditions. The resulting cask structure is then used to show its compliance with IAEA-transport-related design requirements.

Taking into account the maximum possible effects on the inner and shielding casks, the impact positions described below have been selected as representative for the analysis and drop tests.

Impact on the side wall, drop test no. 1. The final disposal cask falls onto the side wall of the shock absorber with its longitudinal axis parallel to the impact plate.

To examine this drop test, shielding and inner casks are analyzed by means of a three dimensional FEM calculation and taking account of non-linear material characteristics. The shock absorbers are also calculated with non-linear characteristic.

The structure has, as starting condition, the drop speed of 13.3 m/s, which results by being dropped from a height of 9 metres. The positions of the strain gauges and the accelerometers were chosen for areas of the cask with the greatest impact loads and expected strains.

In total, 33 strain gauges and nine accelerometers were installed for the inner cask (leaktightness of enclosure of this type B(U) cask), and 19 strain gauges and 11 accelerometers were installed for the outer cask. To record the values measured during the drop tests, two independent channel data recording devices (SCP 3200 from the firm of Krenz) were used. The SCP 3200 system was specially designed to record measured values from strain gauges and piezoelectric accelerometers.

Impact on the lid, drop test no. 2. The final disposal cask falls on the shock absorber with its longitudinal axis perpendicular to the impact plate.

Impact on the edge of the lid, drop test no. 3. The final disposal cask is dropped onto the corner of the shock absorber with the diagonals of its center of gravity perpendicular to the impact plate.

Stress Analysis for 5-Metre Drop Tests Without Shock Absorbers

Impact on the trunnions, drop test no. 4. The final disposal cask falls onto both trunnions simultaneously with its longitudinal axis parallel to the impact plate (concrete foundation), without shock absorbers.
The method of calculation corresponds to that of drop test no. 1, but with the difference that the trunnions are modeled as shock absorber with non-linear material characteristics.

Impact on cask bottom, drop test no. 5. The final disposal cask falls with its bottom to the impact plate (concrete foundation), without shock absorbers.

Post test program. After the drop test series a post inspection program was performed to verify the mechanical status and tightness of the primary barrier. The welding was inspected by ultrasonic, and the results were compared with the results of the ultrasonic-inspection before the drop tests. Furthermore the welding was inspected by a He-leaktest procedure.

After all these tests, there were no indications of any distortion on the inner cask and the welding zone.

SUMMARY OF THE PRESENT STATUS OF DEVELOPMENT

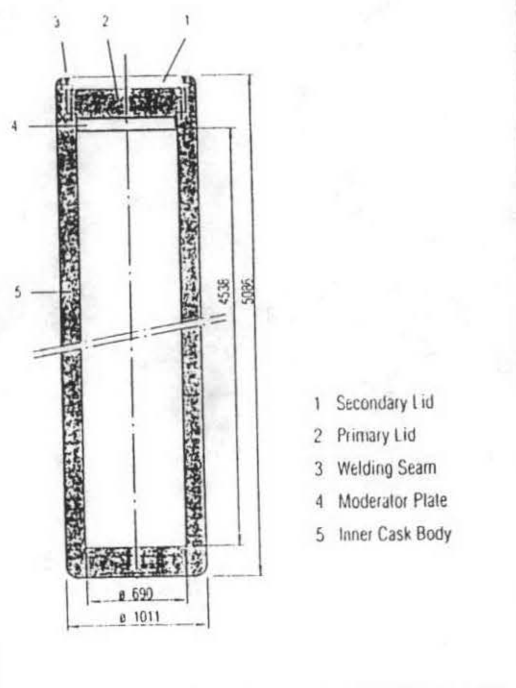
The safety analysis report and the approval documents for the final disposal cask were submitted to the authorities (BAM and BfS) to obtain a type B(U) license and the approval for the storage of radioactive materials in an interim storage facility.

To achieve leaktightness of the inner cask in accordance with final disposal conditions, 1:1 welding tests were performed for the secondary lid. The narrow-gap welding technique used on nuclear power plant components was selected as the suitable welding technique.

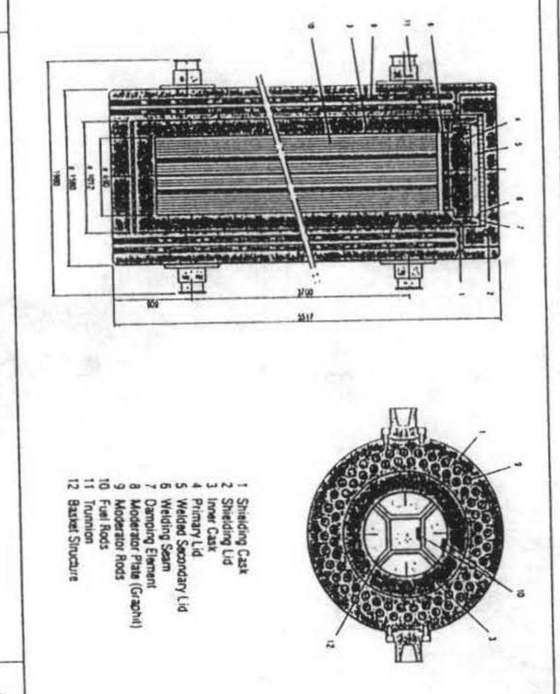
The process tests for the welding technique including ultrasonic tests were performed under the supervision of the German Technical Inspectorate (TÜV) and the authority (BAM), and received a positive assessment. Within this scope, the weld of the test cask was subjected to intensive metallographic examinations.

To prove the analytically performed verifications and to provide verification of the ANSIS FEM program used for calculation of the mechanical tensile strength in accidents (e.g., drop from a height of 9 metres onto an inflexible base), 1:1 drop tests were successfully performed by BAM in 1994. On the basis of these tests we expect no difficulties in obtaining approval for the final disposal cask.

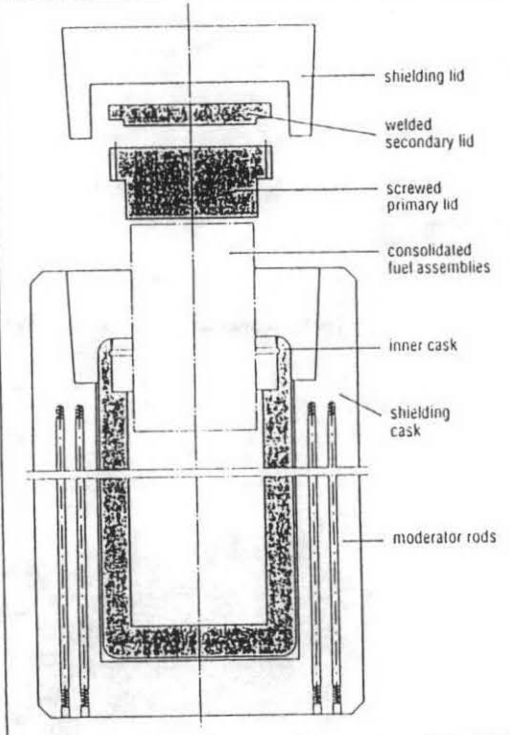
We expect to receive the type B(U) license for the final disposal cask at the end of 1996 and the approval for storage for the interim storage plant in the middle of 1997.



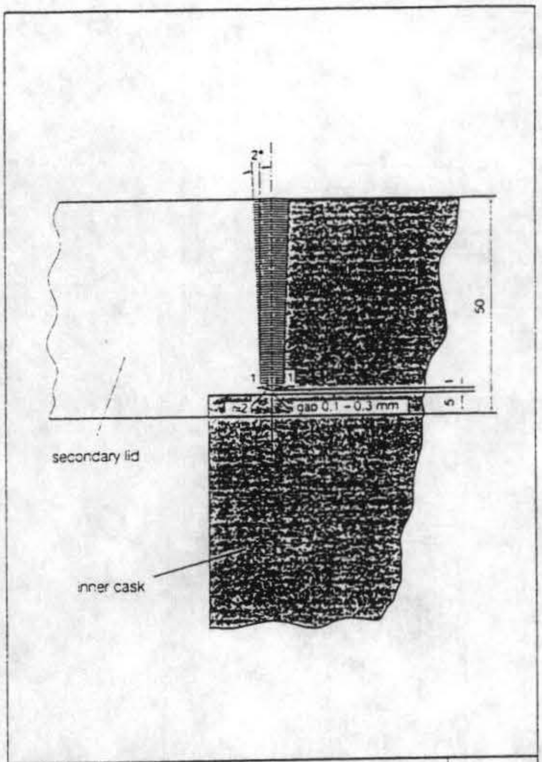
GNB | Inner Cask | Fig 3



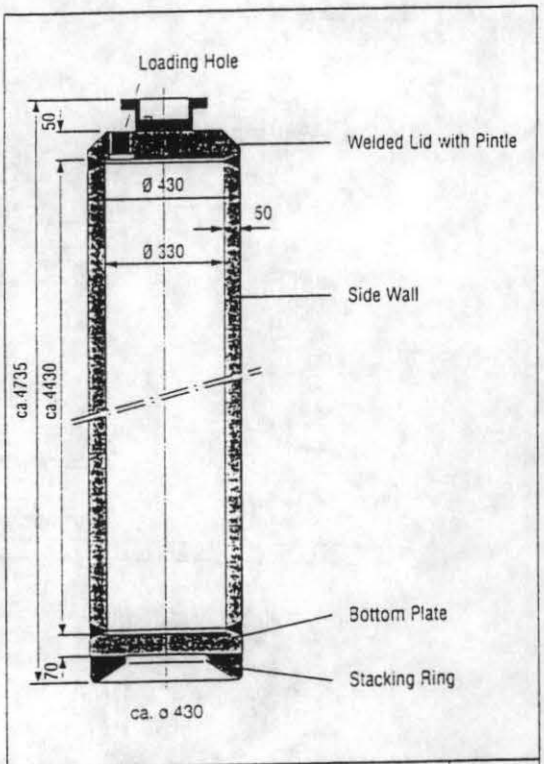
GNB | Final Disposal Cask | Fig 2



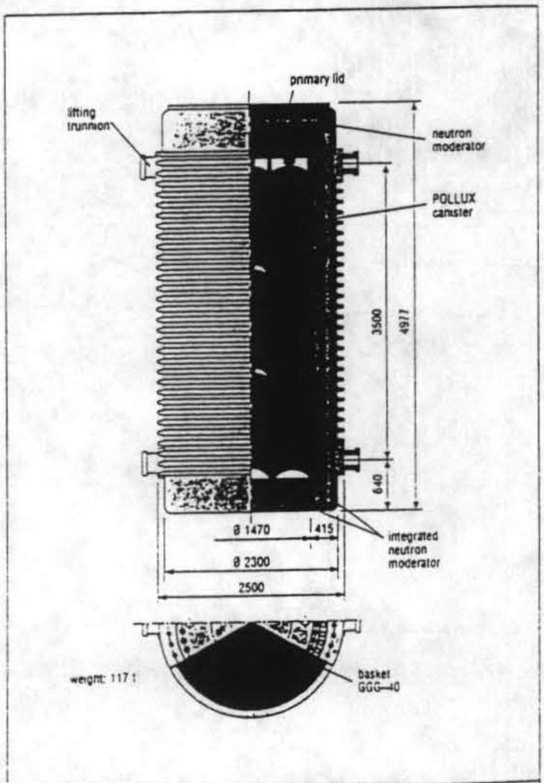
GNB | Final Disposal Cask Containment Concept | Fig 1



GNB | Structure of Secondary Lid Welding Seam | Fig. 4



GNB | Final Disposal Canister | Fig. 5



GNB | Transport- and Storage-Cask for 7/21 POLLUX-Canister | Fig. 6