The German Cask-Concept for Intermediate Storage and Final Disposal of Spent Fuel

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1. Introduction

Based on a governmental resolution of the disposal of wastes from nuclear power stations in Germany, development work has been done since 1979 in the field of direct final disposal of spent fuel. In the period from 1981 to 1984, in the scope of the program "Other disposal techniques" (funded by BMFT, Federal Ministry of Research and Technology), the necessary work was performed to study the technical feasibility of this solution and establish a safety evaluation in order to be able to consider this solution as an alternate to reprocessing (see fig. 1).

The results of this above-mentioned R + D work are the presented two containers

- POLLUX final disposal cask for storage in drifts and
- POLLUX canister for final storage in bore-holes

These casks are designed to cover spent fuel for the direct final disposal which cannot be reprocessed for technical and economic reasons.

The conditions for planning and design of the final dispoal cask and canister were chosen in such a way that the disposal of U- and MOX-fuel assemblies with high burn-ups is also possible.

The principle of the conditioning procedure for the fuelpins is shown in fig. 2.

The schematic arrangement of the Gorleben salt-mine being used as a repository of nuclear waste is shown in fig. 3.

2. Design requirements and conditions for final storage casks

The following requirements must be met by final disposal casks and canisters:

- Guarantee of safe containment of the radioactive material
  - o during conditioning, handling operations, transports and interim storage
  - o during the operating phase in the final repository and after closure of the final repository

- Guarantee of adequate shielding
  - o during above ground handling and storage
  - o during handling in the repository
- Transport and handling capability
- Suitability for final disposal in salt mine.

A standard PWR fuel element was taken as a design basis, which has the characteristics shown in table 1.

The PWR fuel element is examined for 3 types of fuel. The types of fuel are listed in table 2.

The "good" Pu-vector represents plutonium resulting from uranium fuel elements with up to 30 GWd/tHM burn-up whereas the "bad" Pu-vector results from uranium fuel elements with up to 40 GWd/tHM burn-up.

The values listed in table 3 are representative for the cycle time and target burn-up.

10 PWR fuel assemblies with a fuel equivalent to approx. 5 t heavy metal were taken as the max. loading quantity for a final disposal cask.
1/2 PWR fuel assembly with a fuel equivalent to approx. 0,27 t heavy metal was taken as a loading quantity for a POLLUX canister.

The cask and the canister must be able to cover the following repository data:

	cask	**canister**
- Repository type	Rock salt	Rock salt
- Reference disposal form	Drifts	Bore-holes
- Corrosion resistance of the storage cask required	Hypothesis: 500 years	50 years
- Temperature inside salt dome	Hypothesis: 200 °C	200 °C
- Maximum container weight during transport	65 t	1 t
- Rock pressure on disposal cask	300 bar	300 bar

For these design conditions, the final disposal cask has to meet the requirements of the international transport regulations, and the licensing demands for an interim disposal site for transport and storage casks.
The POLLUX canister will be stored in a special storage cask until the time of final disposal.

3. Design of the POLLUX final storage cask

Fig. 4 shows the principal design of the final disposal cask concept.

The material to be disposed will be stored in packed canisters.

Fig. 5 shows the design of the final disposal cask more in detail.

3.1 Base body

The cylindrical side wall including the bottom of the final disposal cask is drawn without a seam out of one piece made of fine-grained construction steel.

The thickness of the cylindrical wall is 160 mm and is designed according to the mechanical and shielding requirements.

3.2 Primary lid

The primary lid of the final disposal cask consists of the same material as the base body. It ensures the sealing function before and during the welding of the secondary lid.

A plate made of neutron moderating and absorbing material is installed under the lid.

The surfaces of the primary lid are precisely machined to accommodate a metallic O-ring and an elastomer seal.

In the primary lid, there is a connection for the filling of the cask interior with helium. Furthermore, there is a test hole to perform a leak test of the seal system. The test hole is closed by means of a plug and a metallic seal.

3.3 Secondary lid

The secondary lid is made as a welding lid consisting of the same material as the base body. It is welded with the base body in the conditioning plant. The welding connection with a thickness of 50 mm constitutes a permanently tight barrier for transport and storage of fuel assemblies (fig. 7). The weld is equivalent to the base material.

3.4 Corrosion protection

The whole final disposal cask can be provided with a long-term corrosion protection on the outside to meet the requirements of final storage.
The corrosion protection design will be selected after the storage requirements of the final repository are defined.

4. Design of the shielding cask

4.1 Base body

The base body of the shielding cask is cast in one piece out of ductile cast iron (DCI). It is designed according to the shielding requirements with a wall thickness of 265 mm.

Two rows of holes with moderator material are arranged in the wall of the shielding cask. Each row consists of 36 holes with a diameter of 80 mm each.
The principal function of the shielding cask is to reduce gamma and neutron dose rates on the surface so that the allowable limit of 0.2 mSv/h for interim storage is met.

Furthermore, in the final repository, the shielding cask takes the loads of isostatic salt rock pressure of 300 bars.

4.2 Lid of the shielding cask

The shielding cask is screwed with a lid provided with trapezoidal threads.

The lid dimensions and the threads are designed in such a way that the loads resulting from service conditions and possible accidents can be withstood.

5. Cask internals

The structure of the basket of the final storage cask is represented in fig. 6. It consists of an inner square-shaped box which has plates at each corner as space dividers. These dividers center the basket structure and provide sufficient heat transfer from the center of the cask to the periphery.

The central square position can be occupied by the fuel rods of two PWR fuel assemblies or with compacted structural parts of fuel assemblies.

Suitably shaped fuel rod canisters with consolidated fuel from 2 PWR fuel assemblies each are placed into the four outer segment locations. These canisters are made as a welded structure.

The canisters as well as the central basket position are closed dust-tight with lids after remote-control loading.

6. Results of shielding and criticality calculations

6.1 Calculated dose rates

Based on the shielding geometry shown idealized in fig. 8 and the OREST burn-up calculations, shielding calculations for the 3 types of fuel assemblies considered with a burn-up of 55 GWd/t heavy metal were performed.

The results of this calculation are shown in the figures 9 and 10. They show the dose rate as a function of the decay time, separated into gamma and neutrons respectively and as a sum curve.

The neutron moderator arrangement is varied as a parameter. The figure also shows that the neutron component is determining for the dose rate after about a 10-year decay time.

6.2 Results of the criticality calculations

The POLLUX cask is designed in such a way that, in case of the most unfavourable incidents and possible accidents, the neutron multiplication factor k_{eff} is below 0.95.

In detail, the following conditions are assumed:

- The fissile material of the fuel assemblies to be conditioned is limited in such a way that the subcriticality remains ensured in case of a flooded interior. Conservatively, fresh nuclear fuel, with the increased initial enrichments shown in table 4, is taken as a basis.

Increased U-235 enrichments or Pu-fissile parts are precautionarily considered as there could be different rod arrangements with individual values above average for special fuel assemblies which should be disposed by means of POLLUX.

- The heavy metal of 2 PWR fuel assemblies is normally loaded in one canister.

7. Results of thermal calculations

The maximum allowable thermal load of the fuel conditioned in the POLLUX cask for the normal interim storage operation results from the following requirements:

- the integrity of the cask and thus the containment of radioactive materials must be guaranteed in the long term,
- the integrity of the fuel cladding must be maintained,
- the temperature of the cask surface (85 °C) stated in the transport regulations for type B(U) should not be exceeded.

To meet with the demand for integrity of the fuel cladding and the containment safety, the maximum heat load, which is transferred by the cask, must be determined as precisely as possible. In other words, the heat transfer behaviour of the cask must be determined starting from the maximum allowable temperature for the creep of the fuel cladding of approx. 390 °C.

Based on the performed burn-up calculations with OREST, the fuel rod temperatures shown in fig. 12 were determined for the 3 considered types of fuels as a function of the decay time.

Fig. 13 shows the temperature distribution through the cask for 3 different planes.

8. Design of the POLLUX canister for final disposal

8.1 General

The POLLUX canister (see fig. 14 and 15) is designed to contain fuel rods from spent LWR fuel assemblies after cutting up in fuel rod sections.
The following design characteristics mark the packing suited for final disposal:

- The outer form and dimensions of the POLLUX canister are the same as for the HAW glass canister for vitrified high-level radioactive wastes from the reprocessing plant. Thus, a joint handling and final disposal of both canister types in bore-holes are possible.
- The capacity of the short POLLUX canister is designed to receive cut fuel rods of alternatively 0.5 PWR or 1.5 BWR fuel assemblies.
- The resulting side wall thicknesses of the POLLUX canister are sufficient to withstand the forces resulting from salt rock pressure during final disposal according to the current status.
- By means of the welding closure of the POLLUX canister after loading, the gas-tight containment of the radioactive material during transport, interim storage and final disposal is ensured.

8.2 Design structure of canister

The POLLUX canister is a cylindrical cask. The design structure and the principal components are represented in fig. 14 and 15. It consists of:

- a hollow-cylindrical canister piece made of steel;
- a welded lid plate with a grapple device;
- a welded bottom plate which has two holes for the loading and ventilation. These bore-holes are closed by means of a primary plug and ventilation valve after loading;
- a filter in the canister interior which is connected with the ventilation opening via the ventilation valve;
- a secondary plate in the bottom welded in the hot cell.

8.3 Loading and intermediate storage

The loading of the POLLUX canister with fuel rod sections of spent LWR fuel assemblies is effected with hot-cell technology in a pilot conditioning plant. The loading principle is shown in fig. 16. After finishing, the canisters are loaded in a transport and storage cask. A special canister cask, which is in a licensing procedure at the moment, is destined as a possible intermediate storage cask for POLLUX canisters (see fig. 17).

9. Summary of results

This paper examined the development of a new final disposal cask system for spent fuel. The POLLUX cask has to comply with international transport regulations (IAEA regulations) as well as the requirements of the German Atomic Energy Law.

A special programme of measurement on a POLLUX prototype cask manufactured to a scale 1 : 1 will be carried out to confirm the design data relevant to the permit required.

The licensing procedure for the POLLUX final disposal cask in Germany is on the way.

Historic development

28.9.1979 Decision of the Head of the Federal and State Governments
- Evaluation of feasibility and safety technology for "Direct Disposal"

1979 – 1980 KfK Report 3000
- Basically feasible
- Research necessary

1981 – 1984 Main R & D work on "Alternative Technologies for the fuel cycle back-end"
- Selection of and engineering work on a reference concept
- Comparison with the integrated fuel cycle back-end (with reprocessing)
  Result: both concepts are equally safe, but further R & D is necessary for direct disposal

1985 – 1993 R & D programme "Direct Disposal"
- Development of direct final disposal up to the application stage
  Financing:
  – conditioning and disposal casks by DWK
  – repository-specific matters by the Federal Ministry of Research and Technology (BMFT)

6.5.1986 DWK files an application for a license according to the Atomic Act to build and operate a pilot conditioning plant at Gorleben

Participating Institutions

Karlsruhe Nuclear Research Centre
- Coordination and systems analysis

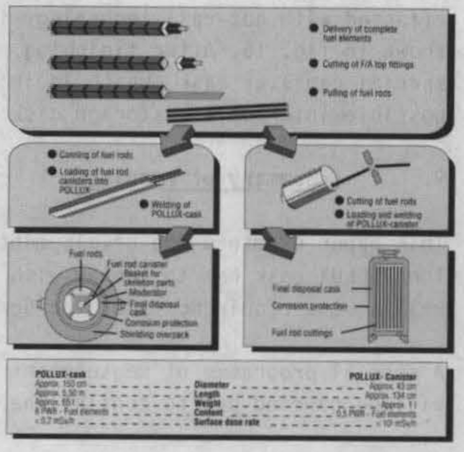
German Society for the Construction and Operation of Repositories for Residues (DBE)
- Final disposal and
- Testing of minig requirements

Society for the Investigation of Radiation and the Environment (GSF)
- Long-term safety of a repository

Federal Agency for Geosciences and Basic Resources (BGR)
- Geomechanics of the salt dome under thermal loads

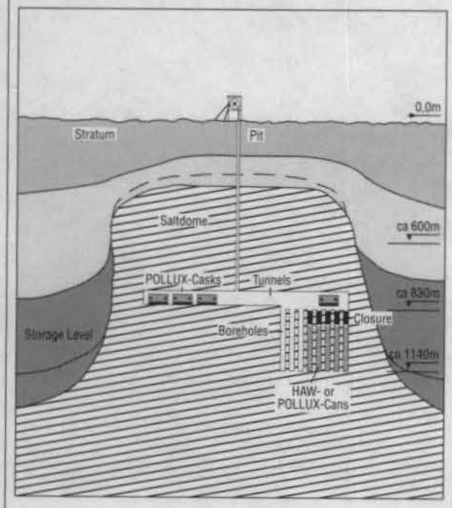
Society for Nuclear Services (GNS)
- Demonstration of conditioning technologies and
- Development of final disposal casks

GNS | Historic Development of "Direct Disposal" | Fig. 1

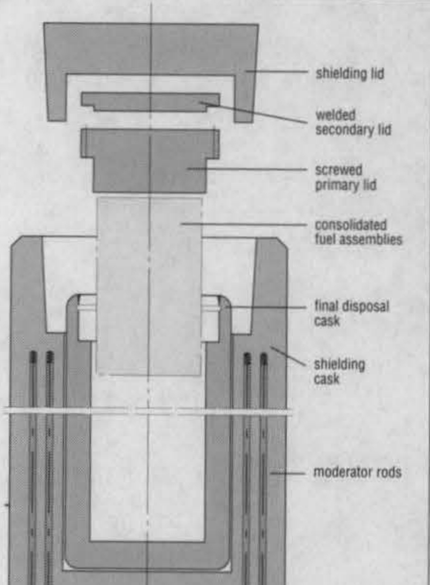


POLLUX-cask		POLLUX- Canister
Approx. 150 cm	**Diameter**	Approx. 43 cm
Approx. 5.50 m	**Length**	Approx. 134 cm
Approx. 65 t	**Weight**	Approx. 1 t
8 PWR - Fuel elements	**Content**	0.5 PWR - Fuel elements
< 0.2 mSv/h	**Surface dose rate**	< 10 mSv/h

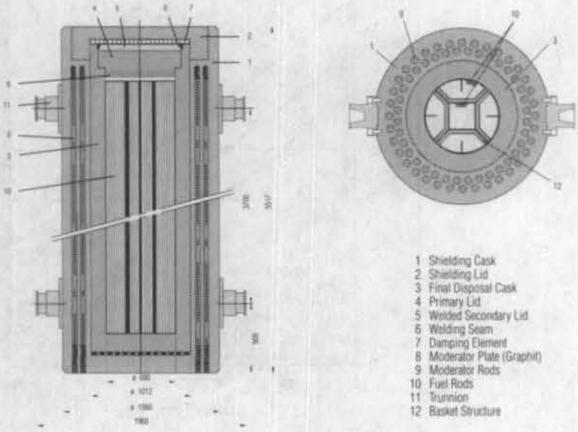
GNS | POLLUX-10 PWR-F/A Internals | Fig. 2



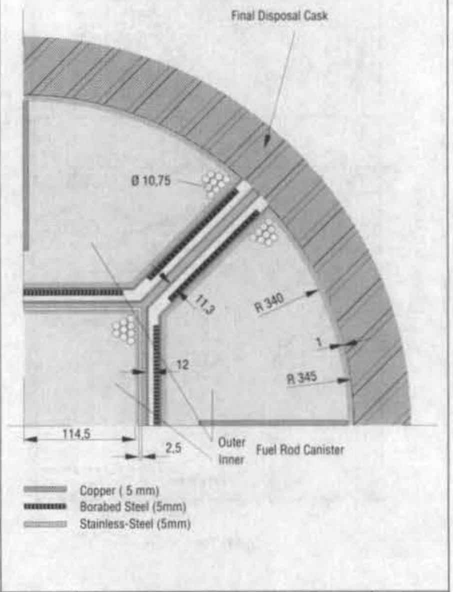
GNS | Schematic arrangement of a saltdome being used as a repository for nuclear waste | Fig. 3



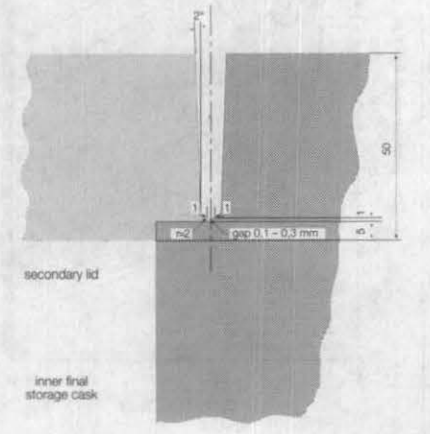
GNS | POLLUX Containment Concept | Fig. 4



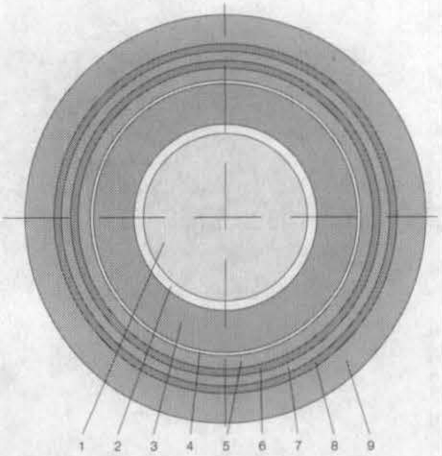
GNS	POLLUX CASK	Fig 5



GNS	POLLUX-10 PWR-F/A Internals	Fig 6



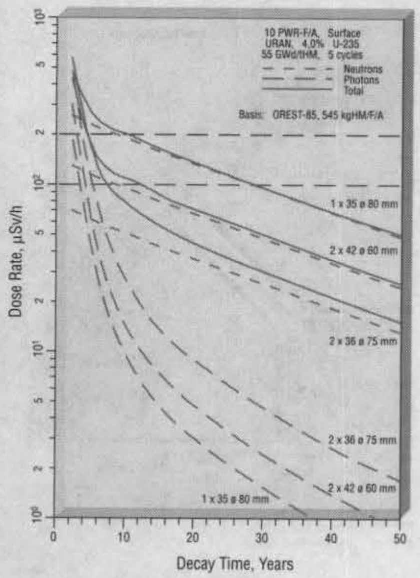
GNS	Structure of Secondary Lid Welding Seam	Fig 7



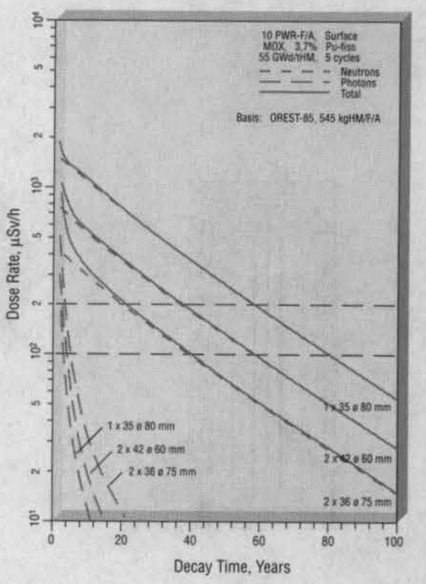
Zone	Material
1	Fuel Pins
2	Gap
3	15 Mn Ni 6 3
4	Gap
5	GGG40
6	Inner Row of Moderator Rods
7*	GGG40
8*	Outer Row of Moderator Rods
9	GGG40

* Cask with two Rows of Moderator Rods only

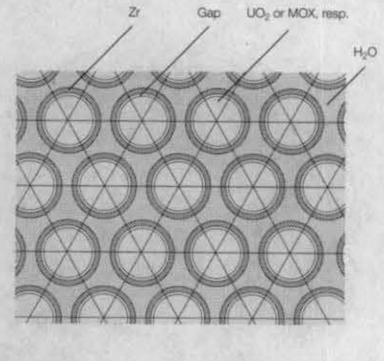
GNS	POLLUX-10 PWR-F/A Radial Shielding Model	Fig 8



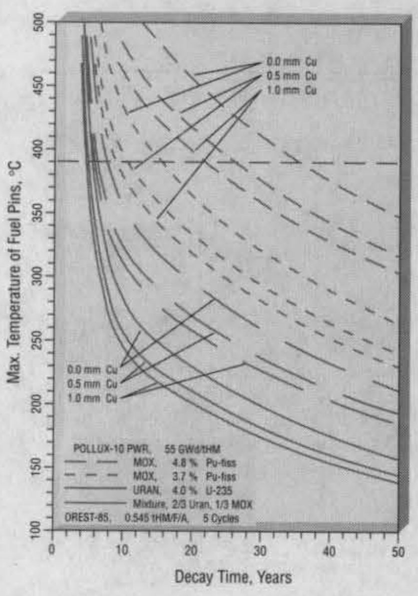
GNS | POLLUX-10 PWR-F/A
Dose Rate at Surface of Cask
Loaded with Fuel Pins from Uran F/A | Fig. 9



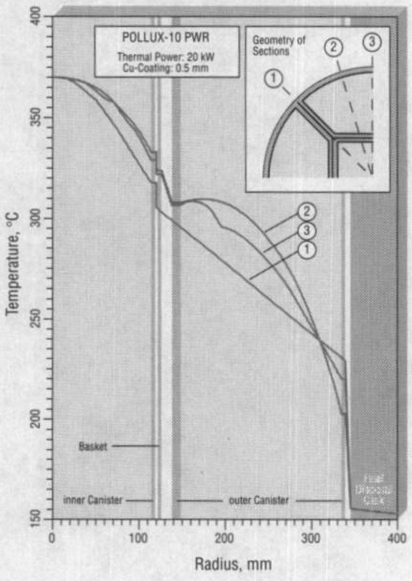
GNS | POLLUX-10 PWR-F/A
Dose Rate at Surface of Cask
Loaded with Fuel Pins from MOX F/A | Fig. 10



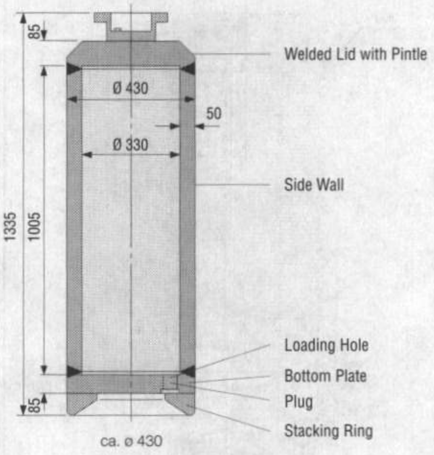
GNS | Hexagonal Fuel Pin Lattice for
Lattice Cell Calculation | Fig. 11



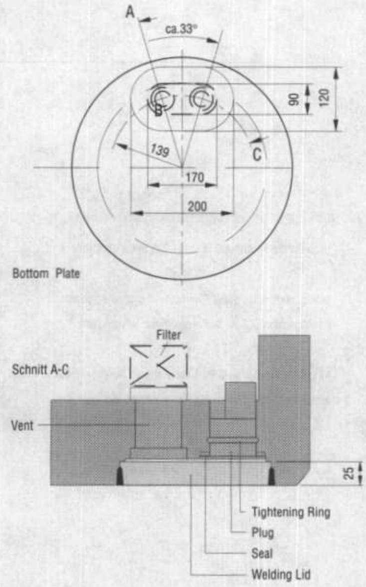
GNS | POLLUX-10 PWR-F/A
Maximum Temperature of Fuel Pins
with Burn-up of 55 GWd/tHM (5 Cycles) | Fig. 12



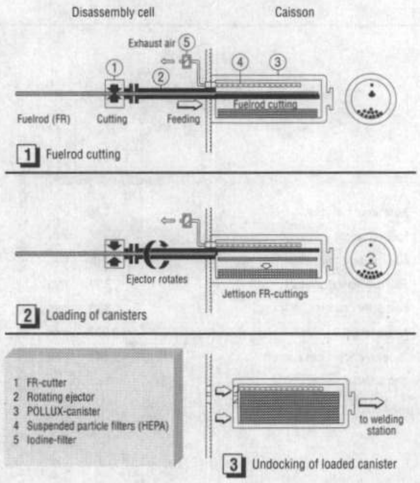
GNS | POLLUX-10 PWR-F/A Temperature Profiles for Different Sections (Insert) of Cask | Fig. 13



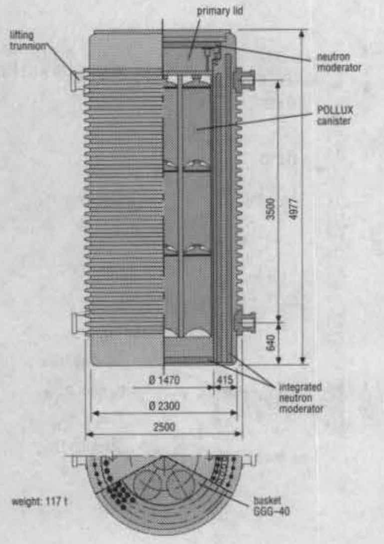
GNS | POLLUX-Canister Over View | Fig. 14



GNS | POLLUX-Canister Sealing System | Fig. 15



GNS | Loading Principle of Unshielded POLLUX Cask | Fig. 16



GNS	Transport- and Storage-Cask for 21 POLLUX-Canister	Fig. 17

Number of fuel pins:	236	
Fuel pin length	4.407	mm
Fuel can outer diameter	10,76	mm
Fuel can inner diameter	9,30	mm
Fuel pellet diameter	9,10	mm
Active length	3.900	mm
Heavy metal per fuel element	< 545	kg
Can material	Zirkaloy	

GNS	Characteristic Data of a Standard PWR Fuel Element	Table 1

- Uranium oxide with 4,0 W.-% U-235 initial enrichment

- Mixed oxide with "good" Pu-vector and an average initial enrichment of 3,7 W.-% Pu-fiss in natural uranium

- Mixed oxide with "bad" Pu-Vector and an Average initial enrichment of 4,8 W.-% Pu-fiss in natural uranium

GNS	Types of Used Fuel	Table 2

- 4 resp. 5 cycles with 1.333 resp. 1.667 days at full power
- 55 GWd/tHM average burn-up

To simulate the max. axial burn-up peak, individual calculations up to 62 GWd/tHM burn-up were performed.

GNS Representative Fuel Burn-up Table 3

- Uranium: 4,5 % U-235
- MOX: 4,2 % Pu-fiss ("good" Pu-vector)
- MOX: 5,3 % Pu-fiss ("bad" Pu-vector)

GNS Initial Enrichments Table 4

POLLUX cask	Fuel	Fuel Pin pitch mm	k_{eff}	σ	$k_{eff} + 2\sigma$
10 DWR-F/A	Uran, 4,5 % U-235	12,18 11,38	0,893 0,780	0,004 0,003	0,900 0,767
	MOX, 4,2 % Pu-fiss "good" PU-vector	12,12 11,38	0,831 0,766	0,003 0,003	0,837 0,772
	MOX, 5,3 % Pu-fiss "bad" Pu-vector	12,12 11,38	0,843 0,797	0,003 0,003	0,849 0,802
12 DWR-F/A	Uran, 4,5 % U-235	12,14 11,45	0,913 0,838	0,003 0,003	0,919 0,845
	MOX, 4,2 % Pu-fiss "good" PU-vector	12,14 11,45	0,860 0,810	0,003 0,003	0,866 0,816
	MOX, 5,3 % Pu-fiss "bad" Pu-vector	12,14 11,45	0,870 0,829	0,003 0,003	0,876 0,834

GNS Comparison of Packing Density and K_{eff} Table 5

Thermal load per cask kW	Shielding cask outer surface °C	Shielding cask inner surface °C	Final disposal cask outer surface °C	Final disposal cask inner surface °C
5	54,6	57,6	70,5	72,7
10	67,8	73,8	97,9	102,4
15	79,5	88,5	122,6	129,3
20	90,1	102,2	145,4	154,4
25	100,1	115,2	166,8	177,9

GNS Cask Temperatures for different Heat loads Table 6