QUANTITY AND MANAGEMENT OF SPENT FUEL OF PROTOTYPE AND RESEARCH REACTORS IN GERMANY

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Introduction

In the past, most of the spent fuel elements of prototype and research reactors in Germany were reprocessed or were transported back to their countries of origin. Currently, there is an agreement with the USA that all spent fuel containing uranium originated from the USA can be returned up until 2019 (core removal 2016). When this agreement is no longer in force, all fuel elements have to be stored and eventually disposed of in Germany. The same applies to the fuel elements which are not covered by this agreement. In Germany, the spent fuels of prototype and research reactors are stored in interim storage facility for up to 40 years. Currently, there is no strategy for their management after this period ends.
Within the scope of an R&D project (project identification number 02 S 8679) sponsored by BMBF (Federal Ministry of Education and Research), DBE TECHNOLOGY GmbH has specified the spent fuels of prototype and research reactors which have to be disposed of in Germany. Based on a description and characterization of these spent fuel elements, casks suitable for final disposal were identified and potential modifications were specified. As a last step, a technical concept for integrating the spent fuels of prototype and research reactors into existing final disposal concepts in salt and in clay was developed. The results of the R&D project are summarized in a final report [1].

Spent fuels of prototype and research reactors for final disposal in Germany

Most of the spent fuels of the prototype and research reactors that are already shut down are reprocessed or have been or will be transported back to their countries of origin. Only the spent fuels of the high temperature reactors AVR (prototype reactor at Jülich) and THTR 300 (Thorium High Temperature Reactor at Hamm-Uentrop), a remaining quantity of spent fuel of the KNK II (compact sodium-cooled nuclear reactor at Karlsruhe) (all of them slightly soluble), some of the fuel rods of the nuclear powered cargo vessel Otto Hahn and the spent fuels of the RFR (research reactor at Rossendorf) are stored at interim storage facilities in Germany [2, 3]. After 2019, the spent fuel elements of the still operating research reactors BER II (experimental reactor Berlin II) and FRMZ (research reactor Mainz) have to be taken into account in the German waste management concept as well [2]. The spent fuel elements of the FRM II (research reactor Munich II) which contain uranium originated from the USA and Russia cannot be returned to the USA and have to be disposed of in Germany [2].

Table 1 shows a comprehensive overview of the spent fuels of the prototype and research reactors [2, 4, 5, 6, 7].

Table 1 Type and amount of spent fuels of the prototype and research reactors in Germany

Prototype and research reactors	Number of spent fuel elements/rods
AVR	288,033 fuel elements
THTR 300	617,606 fuel elements
KNK II	2,484 fuel rods
Otto Hahn	52 fuel rods
RFR	951 fuel elements and
BER II	287 fuel elements
FRMZ	89 fuel elements
FRM II	190 fuel elements

In the following, these spent fuel elements/rods are briefly characterized:

- Spent fuel elements of the high temperature reactors AVR and THTR 300 are spherical fuel compacts, each 6 cm in diameter with particles of U-235 and Th-232 fuel embedded in a graphite matrix with a total mass of approx. 214 g (AVR) and approx. 203 g (THTR 300). Each fuel element of the AVR contains 1 g U-235 (enrichment 93 %) and a maximum of 10 g Th-235 or 1.4 g U-235 (enrichment 17 %). The fuel elements of the THTR 300 contain 0.96 g U-235 (enrichment 93 %) and approx. 10.2 g Th-232. [4]
- 2,413 spent fuel rods of the KNK II are from 27 fuel elements with U-/Pu-mixed fuel with a maximum enrichment of 93 % U-235 and approx. 35 % Pu. 71 spent fuel rods with U-/Pu-carbide fuel from the European research program fast breeder have an enrichment of 93 % U-235 and 30 % Pu. [5]
- The 52 fuel rods of the the nuclear powered cargo vessel Otto Hahn contain uranium with an enrichment of 6.6 % U-235. [5]
- The RFR used three different types of fuel elements. The type EK-10 with an enrichment of 10 % U-235 in an UO_2-Mg fuel matrix and the types WWRM and WWRM-2 with an enrichment of 36 % U-235 in an UO_2-Al dispersion fuel matrix. The difference between WWRM and WWRM-2 is a higher ratio of fissile material in WWRM-2 fuels. [6]
- The fuel elements of the BER II contain only low-enriched uranium with an enrichment of approx. 20 % U-235. [2]
- The fuel material of the FRMZ is UZrH with 8 weight-% uranium, with an enrichment of approx. 20 % U-235, 91 weight-% zirconium and 1 weight-% hydrogen. The fuel elements have a thick cladding of aluminium or steel. [8]
- The fuel elements of the FRM II contain uranium with an enrichment of 93 % U-235 in an U_3Si_2-aluminium dispersion fuel matrix. A fuel element contains 7,500 g U-235 and a total of 8,100 g uranium. [9]

Casks for the final disposal of the spent fuels of prototype and research reactors

An initial survey of potential casks for the final disposal of the spent fuel of prototype and research reactors shows that multi-purpose casks (CASTOR®) may be used. Alternatively, fuel rod canisters, so-called BSK, could be used.

CASTOR® casks have cylindrical bodies of cast iron with spheroidal graphite. Each CASTOR® has two individual shielding lids (primary and secondary lid) of cast iron or non-alloy steel [10]. A CASTOR® cask can be loaded either with fuel elements or with fuel canisters:

- A CASTOR® THTR/AVR can be loaded with one fuel canister with approx. 2,100 spent fuel elements of the THTR 300 or two fuel canisters with a total of approx. 1,900 spent fuel elements of the AVR.
- A CASTOR® KNK can be loaded with 9 Phenix canisters with spent fuels of the KNK II or 8 Phenix canisters and 1 OH canister with spent fuel of the nuclear powered ship Otto Hahn
- A CASTOR® MTR 2 can be loaded with spent fuel elements of the RFR, spent fuel elements of the BER II, spent fuel elements of the FRMZ ,and spent fuel elements of the FRM II.

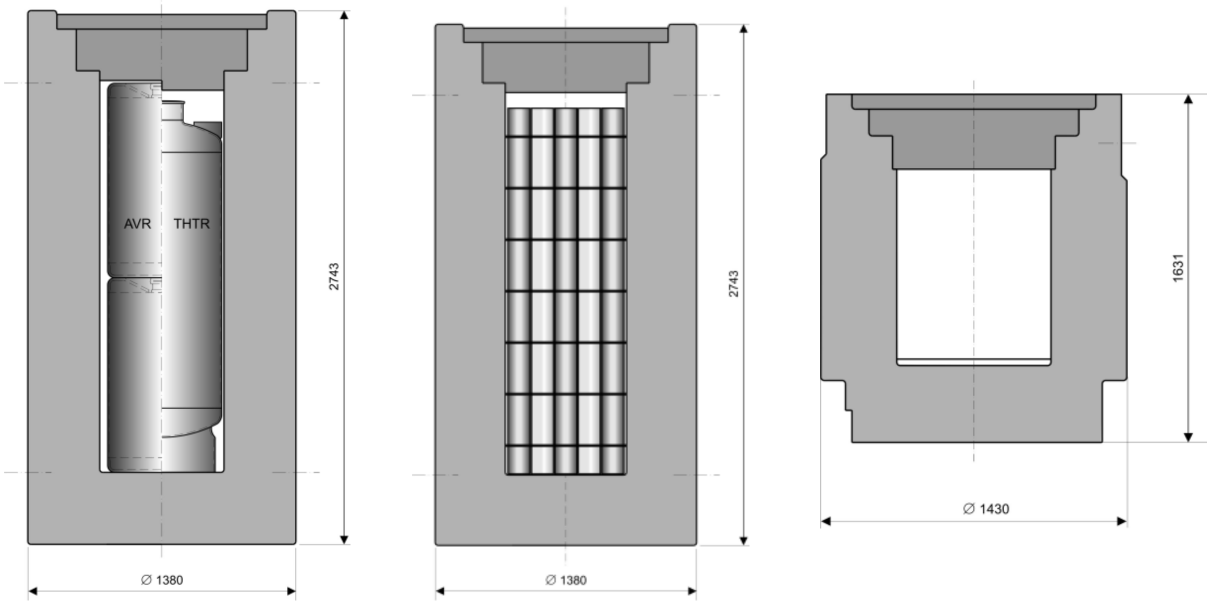

Figure 1: CASTOR® THTR/AVR, CASTOR® KNK und CASTOR® MTR 2 (left to right)

The BSK has a cylindrical canister body with a wall thickness of 40 mm and a pressed-on or welded bottom. The canister body, the primary lid, and the secondary lid are made of fine-grained steel. For handling, the secondary lid has a load-bearing attachment point. A BSK has a height of 4,980 mm and a diameter of 430 mm [11]. The loading of the BSK was calculated based on the geometry of the BSK without taking into account subcriticality. The BSK can be loaded with spherical fuel elements of the AVR and THTR 300, Phenix and OH canisters or fuel elements of the RFR, spent fuel elements of the BER II, spent fuel elements of the FRMZ and spent fuel elements of the FRM II.

In addition to the BSK for the fuel canisters of the AVR/THTR spent fuel elements, a so-called modified BSK with a height of 4,980 mm and a diameter of 705 mm was considered. The modified BSK can be loaded with 4 fuel canisters with fuel elements of the AVR or 2 fuel canisters with fuel elements of the THTR 300.

Neither the CASTOR® cask nor the BSK/modified BSK have been designed in detail or licensed for final disposal. Important safety relevant issues like subcriticality, tightness, and the long-term safety of the casks still need to be studied and analysed.

Table 2 shows the number of CASTOR® and BSK/modified BSK for all spent fuels of prototype and research reactors.

Figure 2: BSK (left) and modified BSK (right)

Table 2 Number of multi-purpose casks and fuel rod canisters for spent fuel of prototype and research reactors

Prototype and Research reactor	Multi-purpose cask		Fuel rod canisters	
	type	number	type	number
AVR	CASTOR® THTR/AVR	152	BSK or modified BSK	152 or 76
THTR-300		305	BSK or modified BSK	305 or 153
KNK	CASTOR® KNK	4	BSK	5
Otto-Hahn				
RFR	CASTOR® MTR2	18	BSK	10
BER-II		9		12
FRMZ		1		1
FRM-II		38		38
Total		527		523 or 295

Integration of spent fuel of prototype and research reactors in existing final disposal concepts in salt and in clay formations

There are two different disposal options for each of the two host rocks salt and clay. The first option is the emplacement of multi-purpose casks (CASTOR®) in horizontal drifts with a length of up to 250 m. The second option is the emplacement of fuel rod canisters (BSK/modified BSK) in vertical boreholes with a depth of up to 300 m (salt) or up to 50 m (clay). In all cases, the temperature in the repository is not to exceed a limit which is 200°C in salt and 100°C in clay.

The technical concepts for the final disposal of fuel elements/rods of prototype and research reactors are similar to those for the final disposal of fuel elements of nuclear power plants. Even the transport and handling procedures are identical. Due to the different dimensions of the casks, however, it is possible that modifications are necessary.

Due to the low heat output of the fuel elements/rods of prototype and research reactors in the CASTOR® casks and the BSK/modified BSK, the respective repository temperature limits are met. Thus, the design of the repository (e.g. drift spacing, casks spacing, borehole spacing) can solely be based on technical aspects. Taking these criteria into account, the emplacement fields for the emplacement of multi-purpose casks in drifts and for the emplacement of fuel rod canisters in boreholes in both host rocks were designed.

Figure 3 shows the emplacement fields for the emplacement of multi-purpose casks in drifts and for the emplacement of fuel rod canister in boreholes in salt. In clay the emplacement field for the emplacement of multi-purpose casks in drifts is similar to the emplacement field in salt. Due to the shorter borehole depth in clay, the emplacement field of fuel rod canisters in boreholes has 10 drifts. For both emplacement fields in clay, the drift spacings and widths are different to those in salt.

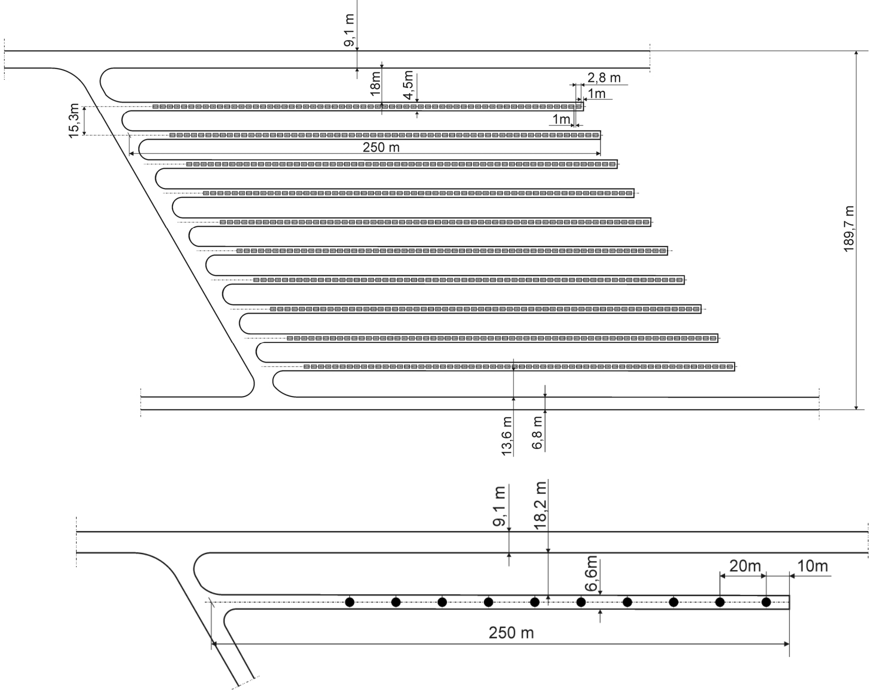

Figure 3: Emplacement fields for the emplacement in drifts (top) and for the emplacement in boreholes (bottom) in salt

Conclusion

All in all, the R&D project showed that the spent fuels of prototype and research reactors can be integrated into existing repository concepts in Germany without major changes.

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