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UNLOADING OF THE REACTOR CORE AND SPENT FUEL MANAGEMENT OF THTR 300

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Abstract

Following granting of License 7/12a on October 22, 1993 and preparatory work, unloading of the THTR pebble bed reactor core was initiated on December 7, 1993.

Achieving the state 'plant free of nuclear material' was one prerequisite for implementation of further preparatory activities to establish safe enclosure. To reach this target, it was necessary to remove approx. 670,000 operating elements (approx. 84% of which were fuel elements).

Basically, unloading of the core was implemented in the same way as removal of the operating elements during duty operation, however, process engineering modifications to the charging system were required due to replacement of the primary gas helium with nitrogen and air and reduced temperature and pressure as compared to duty operation.
During unloading operation, the operating elements were sorted by means of the burn-up measuring system and were transferred into operating element containers (steel cans), 2,100 elements per container.

Insertion of absorber rods and addition of unirradiated absorber elements ensured clearly subcritical conditions at any moment during unloading of the core, which was confirmed by the measured values of neutron flux density.

The residual inventory of fissile material remaining in the reactor pressure vessel after completion of core unloading activities by December 1994 is 0.976 kg and is thus significantly lower than the required value of 2.5 kg.

Due to the limited storage capacities of the plant, it was necessary to ship the fuel element containers simultaneously with core unloading. In a remote-controlled process, the fuel element containers were transferred from the spent fuel store to a shielded loading station, loaded into one transport and storage cask of the CASTOR THTR/AVR-type each, which was then sealed with the primary lid. Following leak testing and definitive sealing by staff working on a working platform outside of the loading station, the transport and storage casks were transferred to six-axle purpose-designed railway wagons and shipped to the Ahaus fuel element interim storage facility (BZA). By April 1995, a total number of approx. 620,000 fuel elements had been transported from THTR to BZA in 57 shipments, on general 6 transport and storage casks on 2 railway wagons per shipment.

Due to actual burn-up of the THTR fuel elements falling below the design values (mean burn-up per fuel element container max. 85,000 MWd/t HM) and the long cooling-down period, dose rates on the casks were very low. Neutron dose rate measurements taken on a loaded transport and storage cask showed results of < 1 μSv/h at the cask surface.

After loading the cask on the transport wagon a gamma dose rate of 1 - 2 μSv/h at the closed transport hood and of 0.5 μSv/h in a distance of 2 m from the transport wagon was measured.

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The dose load received by the personnel was very low during the complete cask handling. The evaluation of the official dosemeters did not either show any of relevant exposure the employees (0.0 mSv/month effective dose).

1. INTRODUCTION

The THTR 300 prototype nuclear power plant in Hamm (Westphalia) with a graphite-moderated and helium-cooled reactor was shut-down for a scheduled revision after an operation time equivalent to 423 days of full-load operation. About one year later, the decision on decommissioning was taken by the federal and state authorities and the shareholders of HKG, the plant operator.

Following granting of License 7/12a on October 22, 1993 and preparatory work, unloading of the THTR pebble bed reactor core was initiated on December 7, 1993.

Achieving the state 'plant free of nuclear fuel' was one prerequisite for implementation of further preparatory activities to establish safe enclosure. To reach this target, it was necessary to remove approx. 670,000 operating elements (approx. 84% of which were fuel elements) from the reactor core (Figure 1), and to ship the fuel elements to the fuel element interim storage facility in Ahaus (BZA).

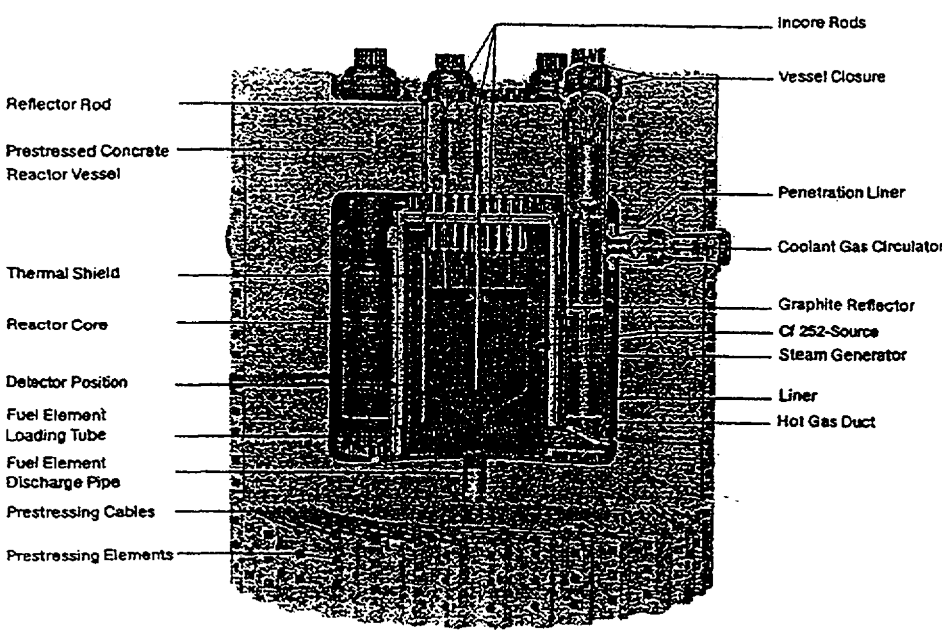


FIG. 1. Reactor vessel of THTR 300 with internals (model)

2. UNLOADING OF THE REACTOR CORE

The reactor core of the THTR 300 consists of a loose bed of spherical elements. At the beginning of unloading operation, the core contained approx. 563,000 fuel elements, 76,000 graphite elements and 31,000 absorber elements. These so-called 'operating elements' are spherical elements with a diameter of 60 mm and consist exclusively or in the main of graphite. Unirradiated fuel elements of the THTR contain approx. 1 g of highly enriched uranium (93% U 235) and approx. 10 g of thorium; the absorber elements and graphite elements used do not contain fuel.

Figure 2 shows diagrammatically the charging system. During duty operation of the plant (September 1985 to September 1988), it was used for continuous charging of the reactor with fuel elements. During this period, the fuel elements were recirculated several times and damaged elements sorted out by the damaged spheres separator.

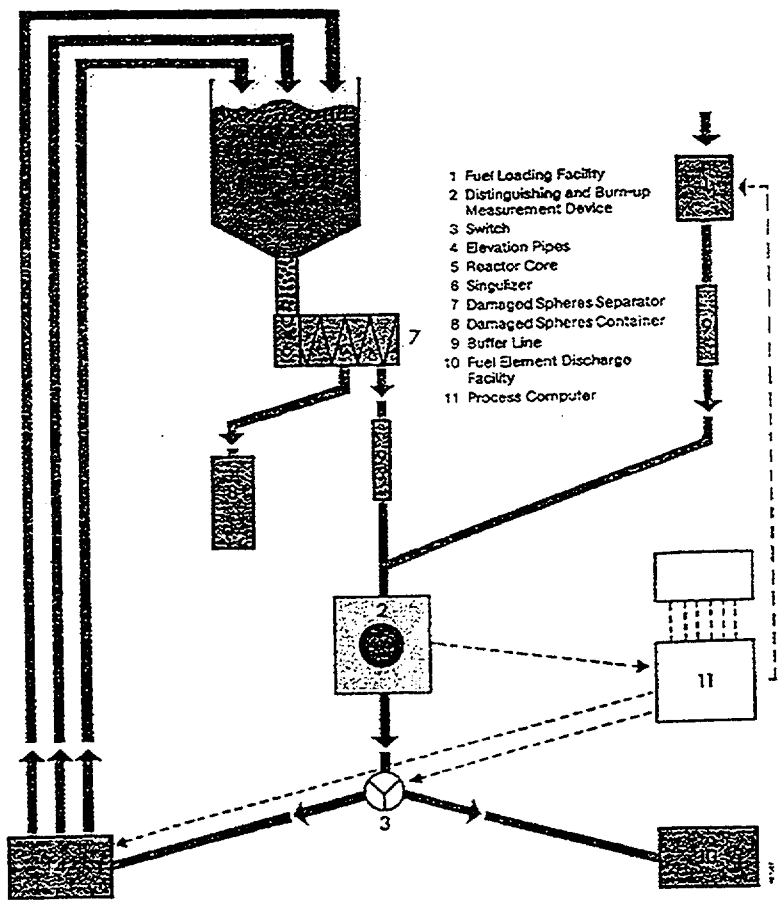


FIG. 2. THTR fuel circulating system

Basically, unloading of the core was implemented in the same way as removal of the operating elements during duty operation; however, process engineering modifications to the charging system were required due to replacement of the primary gas helium with nitrogen and air and reduced temperature and pressure as compared to duty operation.

During unloading operation (December 1993 – October 1994), the operating elements were sorted by means of the burnup measuring system (conisting of a graphite-moderated reactor with a thermal output of 500 W and an evaluating process control computer) and transferred into operating element containers (steel cans), 2,100 elements per container. Balancing of the removed fuel elements was carried out by means of the process control computer of the charging system and, independently from it, by means of the pebble counters of the charging and outward transfer installations.

From the beginning, core unloading was organized as a three-shift operation with seven working days per week. Due to the fact that only a few interruptions due to malfunction occurred, requiring only short periods for repair, and a well-trained staff was on duty, it was possible to remove an average of approx. 2,500 operating elements per day.

Figure 3 shows the distribution of graphite and absorber elements and of the burnup of fuel elements during unloading operation. Unloading steps, each one corresponding to unloading of 2,100 fuel elements, are plotted as abscissa. Burnup is stated in 'fima' (fissions per initial metal atom).

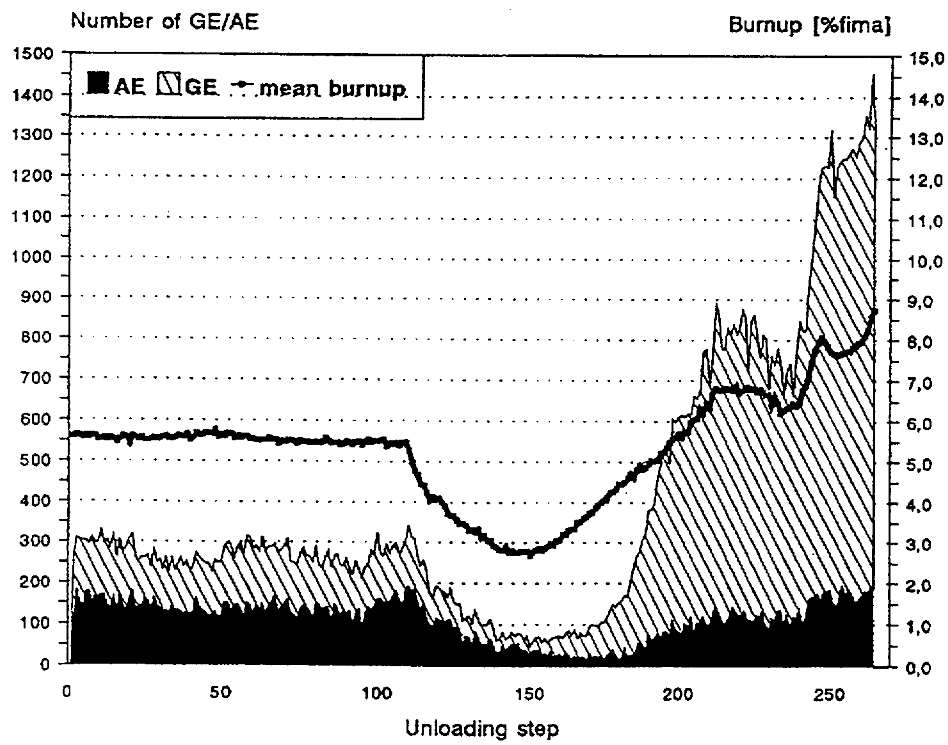


FIG. 3. Number of removed graphite and absorber elements per charge of a fuel element container and mean burnup of the fuel elements.

The diagram reflects the sequence of removal of elements from certain core sectors. The minimum in the area of unloading step 150 is due to removal of fuel elements from the surface of the outer core (low irradiation of fuel elements), the maximum at the end of unloading operation is due to unloading of graphite elements and intensely irradiated fuel elements from the bottom edge of the core. The determined relative shares of operating element types and their variations during unloading time correspond well with the results of model experiments.

Fully inserted absorber rods and addition of a total of approx. 4,200 unirradiated absorber elements at certain unloading steps ensured clearly subcritical conditions at any moment during unloading of the core, which was confirmed by the measured values of neutron flux density.

The development of neutron flux densities during the unloading period is shown in Figure 4. The decrease corresponds to the radioactive decay of the neutron source (Cf 252-source). When the core surface comes closer to the position of the neutron source, the decrease accelerates due to influences of geometry. Finally, only the neutron flux density caused directly by the source remains.

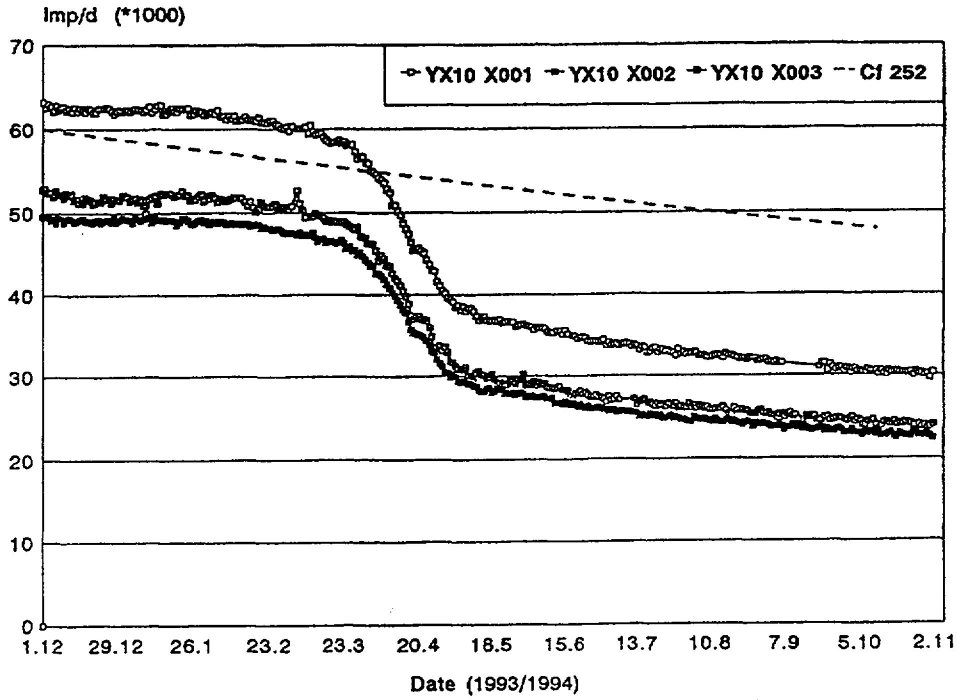


FIG. 4. Neutron flux measurement with three detectors of the YX10 system. (as reference: decay of Cf 252, normalized by arbitration)

Images supplied by a video camera that had been brought into the reactor core from time to time showed that the gradient of the funnel during reactor core discharge was within expectations.

During the final inspection, some operating elements were removed from the lower part of the operating element discharge tube and pushed into the containers provided for damaged fuel elements. Altogether 14 containers for damaged operating elements were filled during the period from the start of operation of the plant until the end of unloading operation.

After the first amendment to license 7/12a had been issued on February 2, 1995, fuel elements that might have been filled into 20 containers during the first year of reactor operation (1985/1986), containing possibly a mix of different types of operating elements, were sorted out and filled into the containers with damaged fuel elements.

The residual inventory of fissile material remaining in the reactor pressure vessel after completion of core unloading activities by December 1994 is 0.976 kg (equivalent to 2,198 irradiated fuel elements) and is thus significantly lower than the required value of 2.5 kg.

3. SPENT FUEL MANAGEMENT OF THTR-300

3.1 Process of the outward transfer of THTR fuel elements

Due to the limited storage capacities of the plant, it was necessary to ship the fuel element containers simultaneously with core unloading. Prior to transport, the fuel element containers had to be transferred into transport and storage casks of the CASTOR THTR/AVR type.

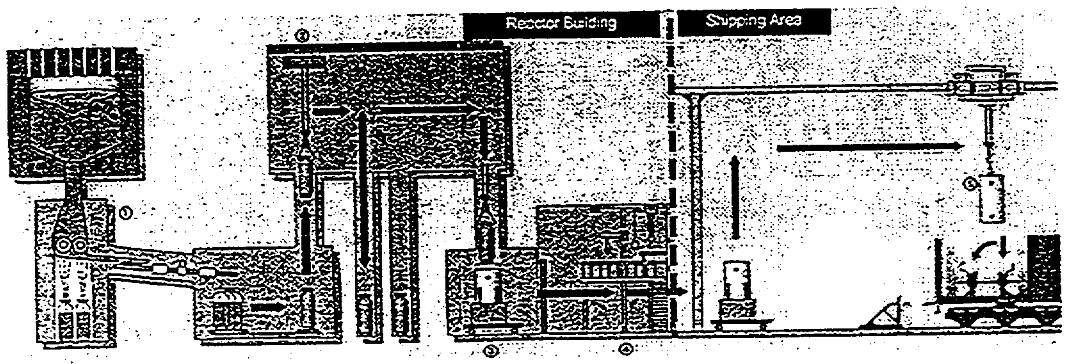


FIG. 5. Process of the outward transfer of the THTR fuel elements
1. Fuel element outlet *2. Crane of operating element store* *3. Loading station*
4. Working platform *5. Transport wagon*

Figure 5 gives a schematic illustration of the process of outward transfer of the THTR fuel elements.

For outward transfer, the transport and storage cask CASTOR THTR/AVR had to be prepared for loading. The cask was opened except for the primary lid and transferred into the loading station. Due to the high dose rate during loading, the shielding gate of the loading station was then closed. By means of the manipulator, the primary lid was removed and the operating element container inserted into the opened transport and storage cask through a ceiling hatch of the loading station from the internal store for operating elements above the loading station. After re-inserting the primary lid into the transport and storage cask and screwing it into place initially by the manipulator, the loading station was opened and after radiological measurements, the cask was transferred from the loading station to the working platform. Here, screwing of the primary lid was completed and the leak-tightness of this first cask barrier (leakage rate $< 1 \cdot 10^{-7}$ mbar $\cdot l \cdot s^{-1}$) proved.

After positioning and screwing of the secondary lid, again the leak-tightness of this second barrier was tested. For transport, the secondary lid was additionally provided with an electronic transport seal. Finally, the protective plate required for interim storage was fitted prior to loading the transport and storage cask onto the transport wagon.

For the shipment of the transport and storage casks to an interim storage facility, HKG has four special six-axle railway wagons at its disposal, each capable of transporting three casks.

Due to HKG's very tight schedule for decommissioning, processing of the transport and storage casks was implemented from the beginning in a multiple-shift operation. Through introduction of 3-shift operation and 6 days working week and through additional optimizing measures during transport and cask handling, a weekly processing rate of max. 11 CASTOR casks was reached.

By April 1995, a total number of approx. 620,000 spent fuel elements had been transported in 305 CASTOR casks from THTR to BZA in 57 shipments, usually six transport and storage casks on 2 railway wagons per shipment.

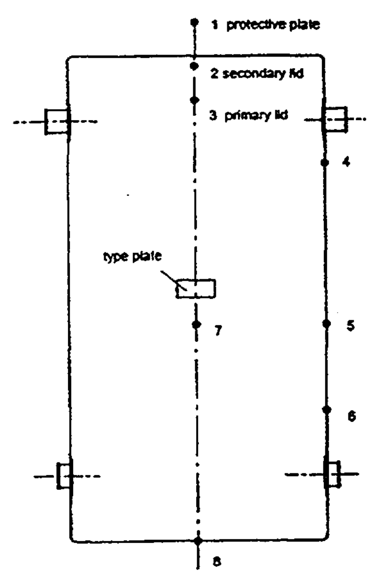
3.2 Exposure of the operating personnel to radiation during cask processing

According to the originally planned burnup and cooling time of the irradiated THTR fuel elements to be stored in the casks (mean/max. burnup 11.4% / 15% fima, 200 days minimum cooling time) a surface dose rate of max. 100 μSv/h (from gamma and neutron radiation) at a 37 cm shielding thickness of the cask material GGG-40 cm had been established in the supply specification.

Due to the real burnup history of the irradiated THTR fuel elements (reduced burnup and longer cooling time prior to storage in the transport and storage casks; max. burnup per fuel element container was approx. 8.8 % fima or 85,000 MW·d/t HM), the dose rate was reduced by about one decimal exponent to below 10 μSv/h. At a measured maximum surface dose rate of a loaded unshielded fuel element container of 10,000 mSv/h, this results in a weakening of the radioactive radiation by a factor of approx. 10^6.

With max. 100 W, the decay heat of the charged fuel element containers also was significantly lower than the design parameters.

Figure 6 shows the typical gamma dose rates measured on the loaded transport and storage cask at various points of a CASTOR cask filled with high-burnup fuel elements.



Measuring Point	Dose Rate
1	0.3 μSv/h
2	1.5 μSv/h
3*	24.0 μSv/h
(open screw holes)	(300 μSv/h)
4	0.4 μSv/h
5	1.8 μSv/h
6	~~0.6 μSv/h~~
7	2.0 μSv/h
8	3.0 μ Sv/h

* only accessible during preparation on the working platform

FIG. 6. Ambient dose rates on transport and storage casks

Measurements of the neutron dose rate at the loaded transport and storage cask after inserting the primary and secondary lid, as well as at the protective plate and at the cask body showed the dose rate to fall below 1 μSv/h.

After loading the cask on the transport wagon, a gamma dose rate of 1 - 2 μSv/h at the closed transport hood and of 0.5 μSv/h in a 2-m distance from the transport wagon was measured.

The total-body doses received by the personnel were monitored with operator-owned digital dosimeters as well as with official dosimeters. The evaluation of the official dosimeters did not either show any measured values at any employees. Measuring results are listed in Table 1.

Table 1. Total-body doses received during cask handling

Year	Number of Casks	Collective Dose [1]			
		Partial-Body Dose [2]		Total-Body Dose [3]	
		Operator's Measurements	Official Measurements	Operator's Measurements	Official Measurements
1992	14	-	-	0,10 mSv	< 0,0 mSv
1993	6	-	-	0,05 mSv	< 0,0 mSv
1994	278	-	38 mSv	0,99 mSv	< 0,0 mSv
1995	7	-	0 mSv	0,01 mSv	< 0,0 mSv

[1] Processing personnel : 10-20 persons
[2] Annual dose limit: 500 mSv/person (dose received during inserting the screws into the screw holes in the primary lid)
[3] Annual dose limit: 50 mSv/person

A comparison of these measuring results with the total-body dose rate limits from Annex X, Table X1, column 2 of the Radiation Protection Act shows that the measured values fall by several decimal exponents below the limits per person laid down in there. This statement is also valid for the partial-body doses that the employees received during inserting the screws into the still open screw holes. Here, monitoring was effected by means of finger badge dosimeters.

4. SUMMARY

The results described above show that based on a good preparation of activities and with a well-trained staff it was possible to carry out at the same time both unloading of a reactor core and shipping of the removed fuel elements to the interim storage site within a short period of time and with very low dose rates.