Dismantling of Primary Shielding with Prototype Machines in a Compact Sodium Cooled Reactor – 15463

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ABSTRACT

The Compact Sodium Cooled Reactor Facility Karlsruhe (KNK), a prototype reactor to demonstrate the Fast Breeder Reactor Technology in Germany, was in operation from 1971 to 1991. The dismantling activities started in 1991. The project aim is the green field in 2020. Most of the reactor internals as well as the primary and secondary cooling loops have already been dismantled. The contaminated sodium inventory has already been disposed of completely. Only the highly activated reactor vessel shielding structures remain. Due to their high dose rates, these structures must be dismantled remotely. For the removal of the primary shielding of the reactor vessel, 12 stacked cast iron blocks with a total mass of 90 Mg and individual masses of up to 15.5 Mg, a remote-controlled multifunctional dismantling device (HWZ) was designed, manufactured and tested in a mock-up. Since it is not possible to remove the segments in one piece for offsite treatment, a special prototype band-saw (BWZ) had to be developed for sawing the segments both horizontally and vertically into smaller pieces. The resulting sub-segments are transferred directly into repository containers.

After the successful approval of the test sequences by the authorities and intensive training of the operational staff, both prototype machines were installed inside the reactor building containment for final assembly. The dismantling started in 2013.

The present paper covers the successful dismantling of the primary shielding as well as the experiences gained through the development, use and improvement of these prototype machines.

INTRODUCTION

The Compact Sodium Cooled Reactor Facility Karlsruhe (KNK) was an experimental nuclear power station with 20 MW of electrical power output [1]. Initially, between 1971 and 1974, the plant was operated with a thermal core and referred to as KNKI. Between 1977 and 1991, it was run with a fast core as KNKII.

The reactor is currently being completely decommissioned and will be dismantled down to green field conditions in ten partial licensing steps according to the German Atomic Energy Act. Under the regulations of the 9th licensing step dismantling of the thermal isolation, removal and cutting of the primary shielding and dismantling the activated parts of the biological shield are being carried out. In a last step all remaining installations such as supply systems, ventilation systems and electrical components will be removed. This removal is necessary for the subsequent release measurement procedure and release from the Atomic Energy Act at the end of the dismantling project. Finally, the buildings will be torn down.

The current status of the KNK decommissioning project in 2015 is that the total sodium inventory has been removed from the reactor. Therefore the subsequent work can be done under normal dismantling conditions without any inertization of the reactor building. Only the activity and the related dose rates as well as the building conditions need to be taken into consideration. Due to the activation during operation the existing dose rates demand a remote-controlled dismantling of the remaining activated part of the primary and biological shielding. (Fig. 1)

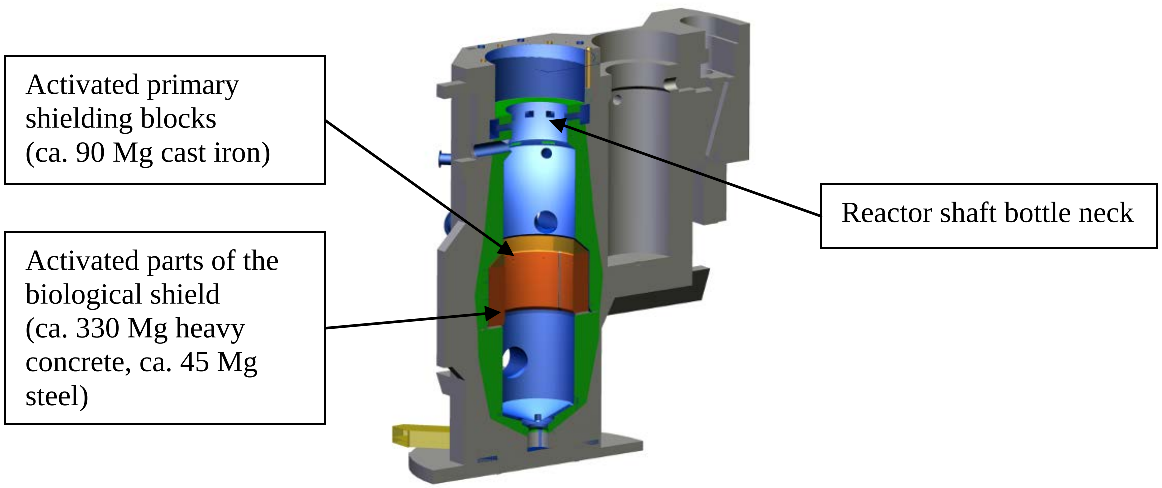

Fig. 1 Setup of the reactor shaft internals with activated parts of primary and biological shielding

The Co-60 activity of the primary shielding blocks is about 1.3 E 13 Bq, respectively 330 mSv/h. Apart from the dose rate the lack of space further complicates the dismantling process. Due to these conditions, it is necessary to develop special machines for the individual dismantling steps to meet the system-dependent requirements. A multifunctional tool, the HWZ, has been designed for the remote-controlled dismantling of the primary shielding.

REMOTE DISMANTLING OF THE KNK PRIMARY SHIELDING BLOCKS

Special Technical Features of the KNK Primary Shielding Blocks

The primary shielding of the KNK reactor shaft consists of 12 modularized cast iron blocks (Fig. 2) with a total mass of 90 Mg and single masses up to 15.5 Mg. The blocks are arranged in a niche that is on a level with the former reactor core. (Fig. 1) The 12 blocks are stacked together and interconnected by means of tongue and groove joints to avoid gaps resulting in direct radiation. One segment contains a measurement chamber filled with lead and a filling piece below the chamber. This configuration requires a certain dismantling sequence.

The shielding blocks do not provide any mechanism for lifting and hook on procedures and are located away from the main crane centerline. All blocks have to be maneuvered through a narrow opening on top of the reactor shaft (bottle neck) with a maximum diameter of 2100 mm (Fig. 1). Some shielding blocks must be rotated up to 90° before they fit through the bottle neck with a clearance of 40 mm.

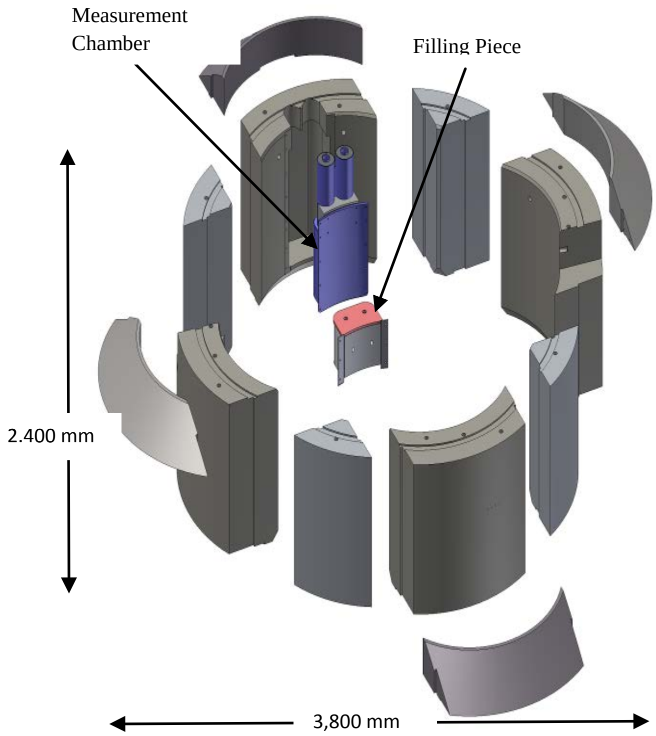

Fig. 2 Principle layout of the primary shielding blocks

THE KNK MULTIFUNCTIONAL SHIELDING BLOCK DISMANTLING DEVICE (HWZ)

General Technical and Functional Requirements

The KNK HWZ must meet the following requirements:

- High availability
- No planned maintenance and in-service inspection
- Technical features for salvage operation
- Actuator redundancy
- Max. payload 16 Mg
- Construction weight limited to 9 Mg with respect to the KNK polar crane payload of 25 Mg

- Construction size limited to 2100 mm with respect to the reactor shaft bottle neck
- Nine degrees of freedom like a 9-axis machine tool
- High repeat and drive up accuracy of all axis under maximum payload
- Automatic and individual remote control of all axis
- Indirect visual control by Closed Circuit Television (CCTV)

Technical Description of the KNK HWZ

According to the dismantling concept, the components of the primary shielding will be lifted out of the reactor shaft one by one. To perform this procedure multiple tasks have to be carried out by the HWZ. As a result of the limited space in the reactor shaft many components had to be designed individually to satisfy the static and spatial requirements. The HWZ is handled within the caisson and reactor shaft with the existing KNK polar crane. The HWZ consists of a heavy steel framework with all systems and actuators being integrated.

The axes are driven by electric motors. Each electric motor has a redundant hydraulic motor in case of malfunction of the electric unit. To lift the cast iron shielding blocks two horizontal core holes (Ø 110 mm, depth 320 mm) have to be drilled into each block. A specially developed drilling system was designed to set the two holes in just one cycle without changing the tool, thus reducing the need of manual interaction. The two milling cutters have been placed in the same way as the two drill rods. This is necessary to get a plane surface before starting the drilling. For visual control of the milling, drilling and clamping process the HWZ is equipped with nine CCTV units.

After placing the lifting holes into the shielding blocks, the drill rods will be exchanged manually in the caisson against so called “clamping mandrels”. The two clamping mandrels will be remotely inserted into the core holes to achieve a firm connection between shielding block and HWZ. The clamping mandrels are spring loaded and hydraulically activated. After fixing the clamping mandrels to the shielding block, the shielding block can be lifted up to transfer the shielding block to the centerline of the reactor shaft and into a position to fit through the reactor shaft bottle neck.

KNK Primary Shielding Block Processing after Remote Dismantling

After remote dismantling of the shielding blocks, the blocks will be cut with a remote-controlled specially designed band saw to fit into special shielding and transfer casks to meet the German repository requirements. For that purpose the blocks will be vertically transferred to the reactor shaft center line and subsequently into the shielding caisson with cask transfer lock. The caisson is positioned above the reactor shaft on the level of the former refueling floor and has already been used for the removal of the thermal isolation. The caisson is heavily shielded and airflow controlled to protect the staff against airborne contamination and radiation impact. Within the caisson the reactor shaft is covered with a remote-controlled reactor shaft cover for ventilation control and radiation shielding from the reactor shaft to protect the staff during eventually needed manual maintenance activities and trouble shooting on the caisson utilities (e.g. cranes, HWZ, band saw, lighting).

KNK Primary Shielding Block Cutting with a Special Functional Band Saw

For the cutting of the primary shielding blocks into sub-segments a prototype band saw had to be developed. The following boundary conditions had to be fulfilled:

- High availability
- Low maintenance requirements
- Actuator redundancy (salvage operation)
- Vertically and horizontally cuttings from different angles
- Grabbing and transportation of the sub-segments by the BWZ
- Control and steerage over camera technology

The purpose of the band saw is to cut the primary shielding blocks into smaller parts to fit into German repository containers. Therefore vertical and horizontal cuttings had to be done. The sub-segments are grabbed by the band-saw and transferred to a specially designed pallet located on an expandable loading station. Two to three sub-segments are put onto one pallet and two pallets are stored into a repository container.

MOCK-UP TEST OF THE HWZ

Due to the complexity of the HWZ and the requirement of the authorities an extensive test program and staff training was planned and successfully executed in the years 2011-2012 in a mock-up test facility. The mock-up is a full-scale model of the former reactor shaft with its relevant geometry. This includes the reactor shaft bottle neck, the niche for the primary shielding blocks as well as five different sizes of shielding blocks and the necessary measurement chamber with filling piece. During the training program the staff was first trained in operation of the HWZ for the remote-controlled dismantling of the shielding blocks under CCTV operation. Subject of the test program was the demonstration of the functionality concerning the geometrical, kinematical and static features of the HWZ and all necessary tasks, such as:

Fig. 3 HWZ during cold tests at mock-up

- Milling and drilling holes into the blocks, wear characteristics of the tools
- Clamping the blocks and lifting them up to the caisson through the bottle neck
- Separate removal of the measurement chamber
- Proving of the salvage operation
- Verification of the arrangements of the CCTV units

During the mock-up tests, it has been shown, that some features needed to be modified and optimized, e.g. for the dismantling of the measurement chamber additional tools had to be developed. Finally it was proven that all tasks can be performed safely as specified before. Additionally important key figures and characteristics were recorded which are necessary for estimation of the total duration of dismantling the primary shielding. In total 4600 man-hours were spent for the cold tests and staff training.

The Progress of the KNK Primary Shielding Block Dismantling

Fig. 4: Milling and drilling of the primary shielding blocks

The dismantling of the primary shielding started in November 2013 with the milling and the drilling (Fig. 4). In January 2014 the removal of the filling piece took place. This was not as easy as during the mock-up testing. The drawings as basis for the mock-up setup showed a gap between the filling piece and the measurement chamber. In reality there was no gap, therefore the removal of the filling piece took longer and was more complicated, but after a longer phase with small movements it could be released. After the removal of the filling piece the measurement chamber could be lowered and removed. After the segmentation of the measurement chamber the removal and cutting of the primary shielding blocks could take place. In 2014 seven of the twelve primary shielding blocks could be lifted out of the reactor shaft (Fig. 5) and be cut into sub-segments. Two of the removed primary shielding blocks had the maximum individual mass of 15.5 Mg. The removal of the pieces was done without any complications.

The cutting of the primary shielding blocks (Fig. 6) was not as easy as during the mock-up

Fig. 5 Lifting up of a primary shielding block

Fig. 6 Cutting of a primary shielding block by using the band saw

testing. During the mock-up testing an average cutting rate of 4 mm/min was achieved. While cutting the activated shielding blocks only an average cutting rate of 1 mm/min could be reached. Since the total length of all cuts is about 80,000 mm an additional cutting time of about 1,000 working hours is needed. The purpose of this is that the activated cast iron is harder than the inactivated material. This is either caused by the neutron flux or by the high temperature variations during operation. Therefore the dismantling of the primary shielding blocks will last until mid of 2015.

CONCLUSIONS

In summary, it becomes apparent, that despite the various challenges, highly complex and individually constructed machines like the KNK HWZ and band saw, are a reasonable solution for ambitious deconstruction measures.