Decommissioning and Dismantling of Prototype Reactors and Fuel Cycle Facilities at the German Karlsruhe Site – Progress and new Challenges

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ABSTRACT

Very recently in June 2009 the decision of the German Government and Federal States Government of Baden-Württemberg to concentrate nuclear decommissioning and waste management activities at the Karlsruhe site under the responsibility of the WAK Decommissioning and Waste Management Gmbh (WAK) was contractually settled. WAK became owner and operator of the waste treatment facilities of the Karlsruher Institut für Technologie (KIT) as well as of the prototype reactors Compact Sodium-Cooled Fast Reactor (KNK) and Multipurpose Reactor (MZFR), both being in an advanced stage of dismantling. Together with the running dismantling and decontamination activities of the former reprocessing facility WAK since 1990, the envisaged demolishing of the R & D reactor FR2 and a hot cell facility all governmentally funded nuclear decommissioning projects at the Karlsruhe site are now being concentrated under the WAK management.

INTRODUCTION

The compact sodium-cooled reactor facility KNK was an experimental nuclear power station with 20 MW of electrical power output. Initially, between 1971 and 1974, the plant was operated with a thermal shaft and referred to as KNKI. Between 1977 and 1991, it was run with a fast shaft as KNKII. The reactor is currently being completely decommissioned down to green field conditions in ten licensing steps according to the German Atomic Law. The current permission step nine includes dismantling of the thermal isolation, removal and cutting of the primary shielding and dismantling of the activated parts of the biological shielding. After finishing these steps, the removal of the remaining auxiliary installations such as ventilation systems or electrical components can take place. This removal is necessary for the subsequent free measurement and release from the Atomic Act at the end of the dismantling project. After release, the demolition of the construction with its built-in components will be carried out.

The MZFR Multi-purpose Research Reactor was shut down in 1984 already. Besides the demolition of the building structure, the major task that still remains to be accomplished is the remote dismantling of the activated part of the biological shield. The various cutting tools and an adapted conventional excavator as a carrier system are being tested. Operation under active conditions is planned to start in the year 2010.

Complete dismantling of the reactor will require eight dismantling steps in total. For each dismantling step, a separate dismantling license had to be applied for. Since early 2007, all licenses needed for MZFR decommissioning to the green field under the Atomic Energy Act have been granted.

The German pilot reprocessing plant WAK was shut down in 1990 and is decided to be dismantled completely until year 2023. A major prerequisite for the complete dismantling of the WAK is the management of the 60 m³ HLLW with a total β/γ-activity of 8E17 Bq resulting from reprocessing.

For this purpose the Karlsruhe Vitrification Plant (VEK) was constructed and started hot operation in 2009 [1].

In parallel to vitrification operation dismantling of the 4 HLLW-tanks in the storage buildings will be prepared for remote dismantling. The HLLW-tanks to be dismantled have a volume of 75 m³ and of 80 m³ respectively. According to the operational history, the tanks have different activity inventory as well as different quantity of deposits remaining after draining of the tanks. The total activity ranges from about 10^{10} Bq up to about 10^{16} Bq. In order to verify these data, one of the HLLW-tanks was inspected, partly rinsed and the dose rates inside and outside the tank measured.. In order to get access to the HLLW tanks as well as to five additional MLLW-tanks, a new access facility was build and set in operation in 2008. Tank dismantling will start beginning of 2010.

This paper will give a comprehensive overview on the technical and organisational measures to handle different nuclear decommissioning projects under one organisational structure. The status and new experiences in the different projects will be presented. The new challenges of the dismantling procedure of highly contaminated HLLW-tanks will be discussed.

DECOMMISSIONING OF THE KNK-REACTOR

The current status of the KNK decommissioning project is that all sodium has been removed from the reactor. Therefore the follow-on works can be done under normal dismantling conditions within a nuclear power plant. This means that only the activity and the corresponding dose rates as well as the building conditions need to be taken into consideration for the dismantling. Due to the activation during operation the existing dose rate demands a remote-controlled dismantling of the shaft internals and the activated part of the biological shield. The Co-60 activity of the thermal isolation is about 6 E11 Bq and that of the primary shielding about 1.3 E13 Bq. Apart from the dose rate, the lack of space further complicates the decommissioning progress.

Figure 1 shows the setup of the remaining parts within the reactor shaft. Above the reactor shaft, an enclosure containing all the necessary tools such as cranes, manipulators and locking systems for the dismantling work was constructed. This enclosure was built for shielding and inerting. The inerting now is no longer necessary since all sodium has been removed, but the necessity for shielding and contamination spread avoidance still exists. Thus the enclosure needs to remain in place.

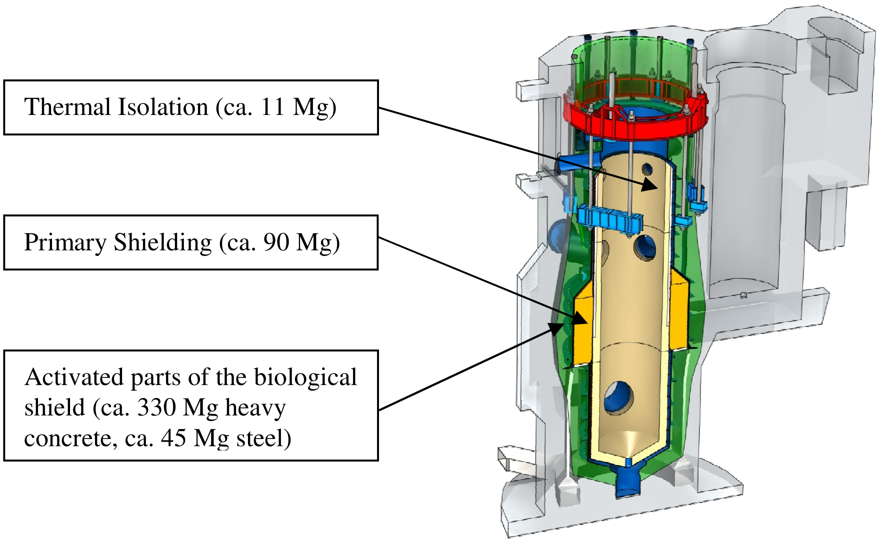


Figure 1: Setup of the shaft internals such as thermal isolation, primary shielding and the activated parts of the biological shield

The thermal isolation consists of a fire brick lining with a thickness of 160 mm in the upper parts and of 250 mm in the lower parts. Only in the upper part of the brick wall there is a 90mm thick layer of rockwool behind the brick lining. The whole brick lining is covered with an 0.5mm thick sheet metal liner. This metal liner is connected to the primary shielding with stud bolts to fix the distance between both components. The total mass of the thermal shielding is about 11 Mg. During dismantling the milling of the thermal isolation is done remote-controlled with standard working tools using a specially designed tool carrier system (see Figure 2). It is equipped with a manipulator system which can be fitted with tools such as a drill hammer and abrasive power cutter.

Figure 2: Tool carrier system with manipulator system and working tools

Cold test of remote handling

The combined use of the tool carrier system, the manipulator system and the working tools was tested inside a specially constructed mock-up. This mock-up is an identical, inactive model of the reactor shaft, where by requirement of the authorities all dismantling steps must be tested and all functionalities must be demonstrated before live use.

During this test some modifications such as additional cameras were made to improve handling and security. The unit has shown its ability to fulfil all required tasks, so that after its installation in the KNK facility in 2010 the full dismantling of the thermal isolation can be carried out. The next step on the way to the final green field status is then achieved.

DISMANTLING OF THE ACTIVATED PART OF THE BIOLOGICAL SHIELD OF THE MZFR-REACTOR

Overview

Dismantling of the plant has advanced well. All former nuclear circuits have been disassembled. Various buildings or building sections have been emptied and decontaminated. Step 7 covering the remote dismantling of the reactor pressure vessel, including internals, was completed successfully in 2007.

The remaining activated components are located in the activated part of the biological shield. These components include the reinforcement and a so-called steel liner that served as a self-supporting permanent sheathing in the construction phase. In addition, 12 measurement chambers are installed radially in the biological shield.

The equipment to be used for dismantling the activated inner part of the biological shield was put up for testing in the former machine hall of the MZFR.

Concept

Remote dismantling of the activated biological shield takes place in three steps that have to be executed successively:

- Phase 1: RC dismantling of the steel liner and cutting of the inner reinforcement layer,
- Phase 2: RC dismantling of the inner layer of the activated concrete of the bioshield (hanging dismantl. rack),
- Phase 3: RC dismantling of the inner layer of the activated concrete of the bioshield (dismantl. rack in the standing position)

All phases are executed using the same dismantling, transportation, handling, and auxiliary equipment. It will be presented in the next section.

Inactive testing of remote dismantling equipment

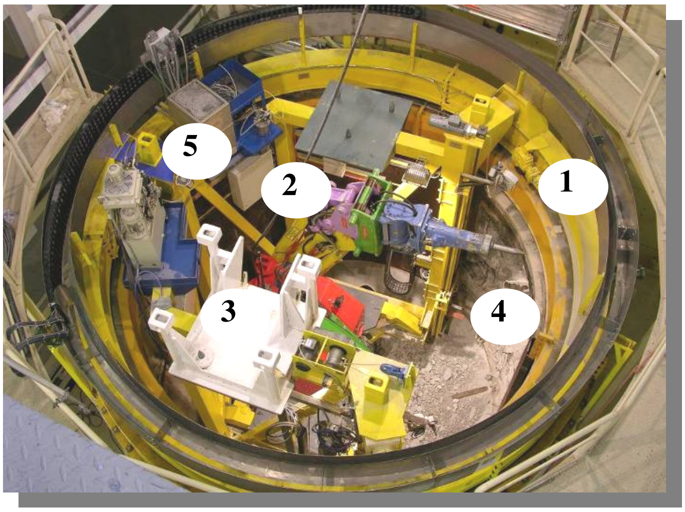
The activated part of the biological shield is dismantled using a remotely controlled excavator as tool carrier system (see Figure 3). It is positioned in the biological shield on a special excavator platform, the hanging and standing rack.

Figure 3: Tool carrier system: RC jack hammer (excavator), an industrial product with a few modifications: supports (instead of chains, 1), adapter for tool uptake (2)

To test the dismantling equipment in the former MZFR machine hall, a representative part of the biological shield was rebuilt in original size (dummy, see Figure 4). In this way, comparability with real dismantling conditions was ensured.

The tests cover all systems and components listed below, which are required for real dismantling:

- A rotating movable carrier ring, from which a hanging rack is suspended as a working platform for the demolition excavator,
- an electrohydraulic demolition excavator, to which various standardized and special dismantling tools can be attached by a rapid-exchange coupling system,
- a remotely controlled master-slave manipulator for supporting work, which can be moved vertically on the hanging rack,
- peripheral devices fixed to the hanging rack, including the surface cleaning device, ultrasonic detection system with marking units, etc.,
- and the complete audio/video system, including all control panels and control units required.



(1) Movable carrier ring
(2) Hanging rack (dismantling rack)
(3) Tool uptake (2 units)
(4) Concrete dummy
(5) Various supply units (hydraulic and electric)

Figure 4: Concrete dismantling of the dummy of the biological shield (test rig)

The demolition excavator, manipulator, and all standardized and special tools were tested in the combined mode. This also allowes an optimization of the dismantling strategy.

The operation staff was trained extensively at the MZFR test rig in using all systems and components, including the demolition excavator and the manipulator. The dummy of the biological shield was dismantled remotely and successively under conditions comparable to later hot dismantling.

Based on this test operation and the experience gained, the equipment and procedures were optimized and qualified.

The major technical objective, i.e. cutting of the steel liner and the inner reinforcing layer, including the inner concrete layer, in a single process was completed successfully.

Installation of the equipment in the controlled area and outlook

After about six months of test operation and acceptance by the inspector present, the equipment was moved to the reactor building in autumn 2009.

In the controlled area, the first systems and devices needed will be commissioned in the presence of the inspector in December 2009.

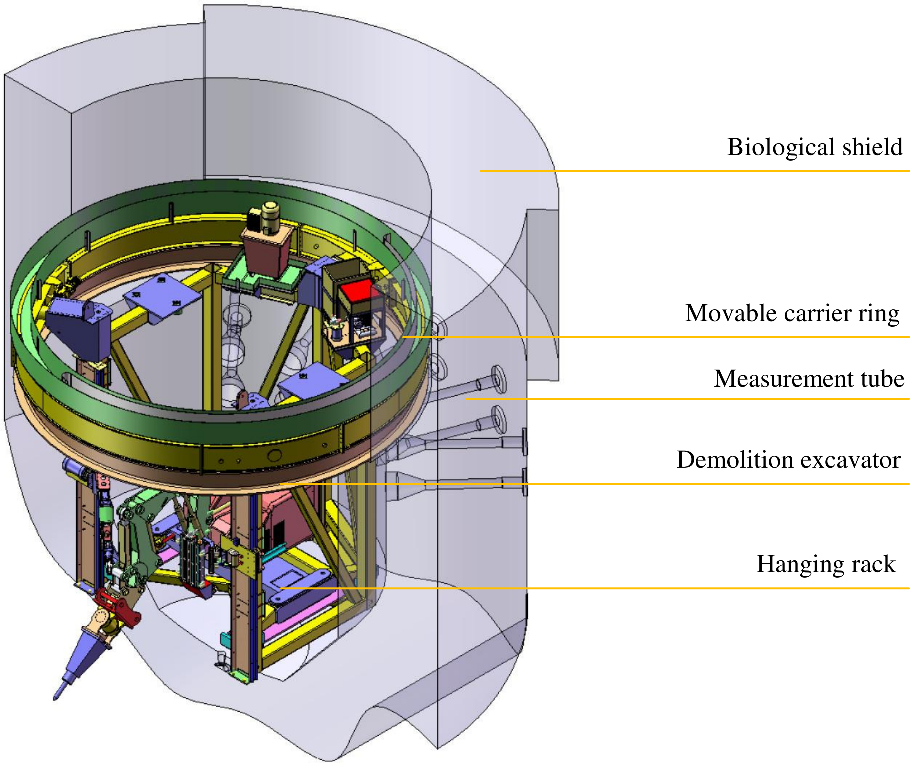


Figure 5: Model of the hanging rack with the demolition excavator in the biological shield

The last activated components of the MZFR will be removed when the biological shield will be dismantled remotely. This work will start in early 2010. The first phase, dismantling of the steel liner, is under preparation. This step is aimed at dismantling the liner that determines the dose rate and the inner reinforcing layer.

Phases 2 and 3 will cover concrete dismantling of the activated biological shield. This work will be also controlled remotely and last about 12 months.

When the biological shield will have been dismantled, infrastructure facilities will be removed successively. Then, all controlled areas will be decontaminated.

Remaining work at the MZFR will include the extensive decontamination of all radiation protection areas and the removal of the H3-contaminated concrete structures.

As a highlight visible from outside, the 99.5 m high exhaust air stack was shortened to +18.5 m in October 2009, see Figure 6. Dismantling of this pure steel stack gave rise to about 50 tons of steel, which were checked for the absence of contamination and then transferred to conventional reuse.

Figure 6: Shorting of the exhaust air stack down to + 18.5 m

DECOMMISSIONING OF WAK REPROCESSING AND HLLW STORAGE FACILITIES

Overview

According to the overall technical concept for decommissioning, dismantling, and disposal of the WAK, decommissioning of the Karlsruhe reprocessing plant (WAK) is divided into six steps (see Figure 7). These steps are largely independent of each other both technically and as far as decommissioning licenses are concerned.

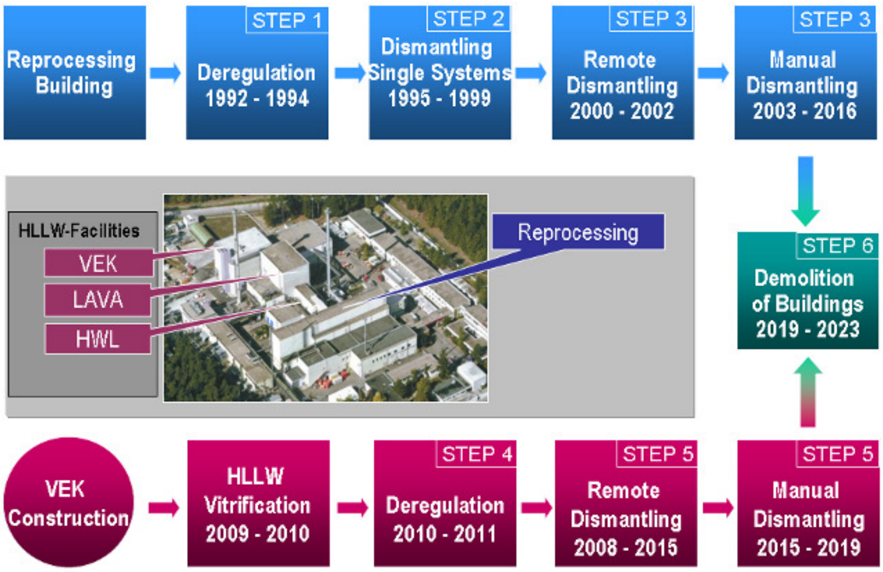


Figure 7: WAK dismantling steps

Steps 1 to 3 comprise dismantling activities in the process building, including the deregulation of the controlled area in the building. Step 4 covers the technical adaptation of the plant after the end of operation of the vitrification facility (VEK). This also includes structural measures to adapt the organization after the completion of VEK operation. Dismantling of the facilities for the storage and treatment of the high level liquid waste concentrates (HLLW) and medium level liquid wastes (MLLW) is covered by dismantling step 5. This includes all measures taken until the deregulation of the controlled areas in the HWL (main waste storage facility) and LAVA (storage and evaporation facility for HLLW) as well as in the VEK and the dismantling of the remaining infrastructure facilities on site. Due to its wide scope, this step is divided into the following 10 dismantling phases (RB = Dismantling step; see Figure. 8):

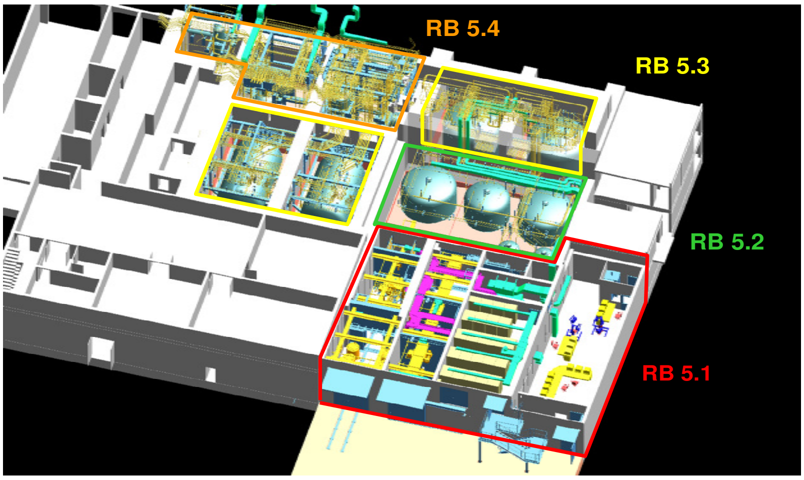


Figure 8: Phases of HLLW tank dismantling

- RB 5.1 Construction and commissioning of the southern extension of the HWL (HWL-annex south)
- RB 5.2 Remote dismantling of the MLLW tanks in the HWL building
- RB 5.3 Remote dismantling of the HLLW tanks in the HWL and the LAVA building
- RB 5.4 Dismantling of the high-active laboratory and remote dismantling of three cells in the LAVA building
- RB 5.5 Manual dismantling of the remaining systems in the HWL, decontamination and release measurement of the building
- RB 5.6 Manual dismantling of the remaining systems in the LAVA, decontamination and release measurement of the building
- RB 5.7 Dismantling of the pipe duct in the ELMA (extension for the storage of medium level waste solutions)
- RB 5.8 Remote dismantling of VEK process technology
- RB 5.9 Manual dismantling of the remaining VEK installations, decontamination and release measurement of the building
- RB 5.10 Dismantling of the remaining infrastructure on site

Step 6 of the overall technical concept covers conventional dismantling of the released building structures.

Remote access to HLLW storage tank hot cells

The first major milestone of step 5 was the commissioning of the newly constructed HWL-Annex South in June 2008 (see Figure 9).

Figure 9: HWL-Annex South

It accommodates various areas for bringing out the dismantling waste and bringing in staff and large devices as well as the control room for the remotely controlled dismantling. In addition, it provides access to the storage areas for the MLLW in the HWL and to the facilities for the storage of the HLLW in the HWL and in the LAVA.
The HWL-Annex South is the major barrier that prevents contamination from being released during the dismantling of the HLLW facilities. The five MLLW and four HLLW tanks can now be dismantled.

Preparations for the dismantling of the MLLW tanks (RB 5.2) started directly after the commissioning of the HWL-annex south in 2008. The first activity performed was the partly remote wall breakthrough to one of the HWL hot cells (see Figure 10).

Figure 10: Remote wall breakthrough to the HWL

The remote handling devices and tools used for this work comprised a manipulator carrier system based on a conventional and accordingly modified small excavator, an electric master-slave manipulator system as well as various small tools.

Boundary conditions for dismantling the HLLW storage tanks

The four HLLW tanks to be dismantled in the HWL and in the LAVA (RB 5.3) have volumes of 75 m³ (two tanks in the HWL) and 80 m³ (two tanks in the LAVA), respectively. Their masses are 16 Mg and 18 Mg, respectively. The thicknesses of the stainless steel walls are 10 mm and 12 mm, respectively.

Only one of the two tanks in the HWL had been filled with approx 600l HLLW for a very short term. After HLLW discharge, this tank was immediately rinsed with fully demineralized water and largely decontaminated. Consequently, no residues are expected to exist in this tank. Based on dose rate measurements, the remaining total activity is estimated to amount to about 10^{10} Bq.

In the second tank, HLLW has been stored for a long time since the beginning of reprocessing in the early 70ies. It is expected that residues from an initial insufficient filtration of the fuel solution as well as from the aqueous phase of the reprocessing process have deposited in this tank. The mass of the residues is estimated to amount to about 100 kg. The total activity inventory is about $6{\cdot}10^{15}$ Bq (Cs activity $2{\cdot}10^{15}$ Bq).

To verify these values which were also used in the licensing procedure for RB 5.3, a HLLW tank in the HWL (see Figure 11) was inspected and rinsed. Then, the dose rate was measured inside and outside of the tank.

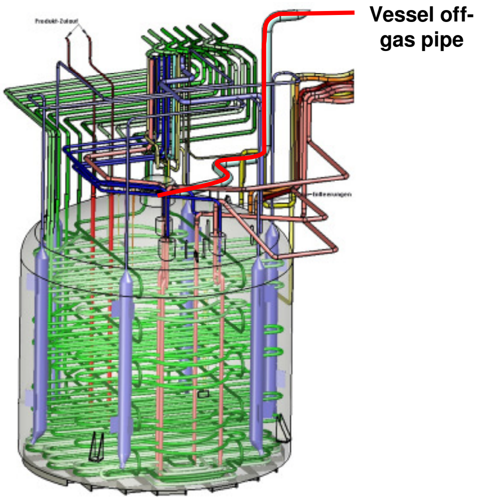


Fig. 11: HLLW tank in the HWL

The tank was accessed via the exhaust gas pipe (DN150, 8 m length, with 5x90° elbow; shown red in Figure 11). For this purpose, an additional nozzle was welded to the pipe. The exhaust gas pipe ends directly in the tank dome which is located centrally on the tank. Via this pipe, a camera system, a dose rate probe, and a rinsing head were inserted into the tank.

At first, the tank was inspected visually using the accordingly adapted camera system. An agglomeration of white residues was found at the bottom of the tank as well as crustaceous residues on the tank internals (pipelines, pulsators, etc.) and the tank wall. Evaluation of the film material confirmed the solid mass of about 100 kg assumed.

Then, dose rate profiles were measured inside and outside of the tank as a function of height. Outside of the tank, maximum dose rates of 5 Sv/h were measured. Inside the tank, the maximum measurement range of the dose rate probes of 100 Sv/h was reached about 1 m above the tank bottom. These values largely confirm the tank activity estimated.

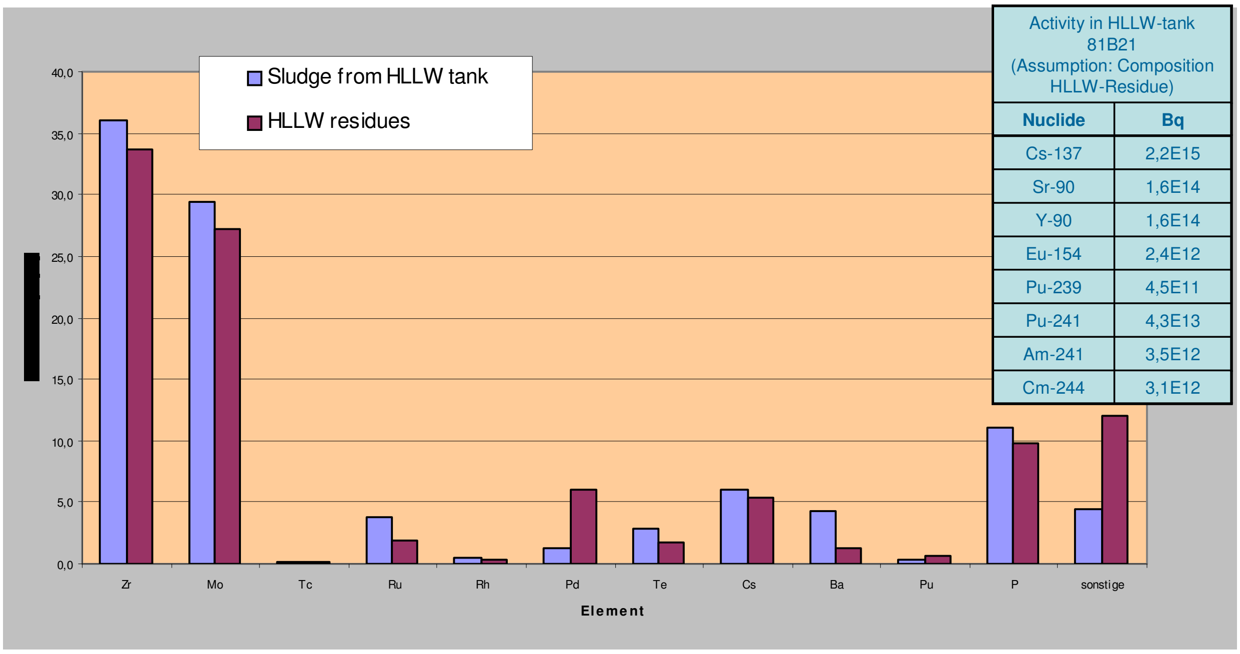
Subsequently, a conventional tank cleaning nozzle was placed in the upper third of the tank to rinse the tank and its internals with about 1 m^3 fully demineralized water.

The success of rinsing was then checked visually and by additional dose rate measurements. The residues on the cooling pipes had been removed partly. In contrast to this, the adhering crusts could not be removed with the rinsing water used. Nor were the deposits at the bottom of the tank affected by rinsing. After the rinsing test, the dose rates measured were only slightly below the first measurements, which may be explained by the water cover of the residues and the associated shielding effect.

In the next step, sampling was carried out using a specially developed sampling system for a small amount of the residues (about 0.1 g) from the tank. With this sampling system finally an amount of about 30 mg of the material has been taken. The dose rates of the taken samples were about 20 mSv.

The samples have been analyzed and resulted in a composition (see Table 1) very much similar to that already known from HLLW residues to be conditioned in the new vitrification facility VEK [1].

Table 1: Relative composition of HLLW residues (HLLW solution and tank deposits)



Activity in HLLW-tank 81B21 (Assumption: Composition HLLW-Residue)	
Nuclide	**Bq**
Cs-137	2,2E15
Sr-90	1,6E14
Y-90	1,6E14
Eu-154	2,4E12
Pu-239	4,5E11
Pu-241	4,3E13
Am-241	3,5E12
Cm-244	3,1E12

Residues are not expected in the storage tanks of LAVA (see Figure 12), in which the HLLW is currently being processed in the VEK vitrification plant. Due to their geometries, the installations for solid suspension, and the effective discharge of the tanks envisaged at the end of vitrification operation, these tanks will be emptied nearly completely. After rinsing, the water will be subjected to vitrification. The remaining residual total activity in the tanks is estimated to amount to about 10^{13} Bq.

The first tank was already emptied end of 2009 after vitrification at app. 30 m³ of highly noble metal containing HLLW [1].

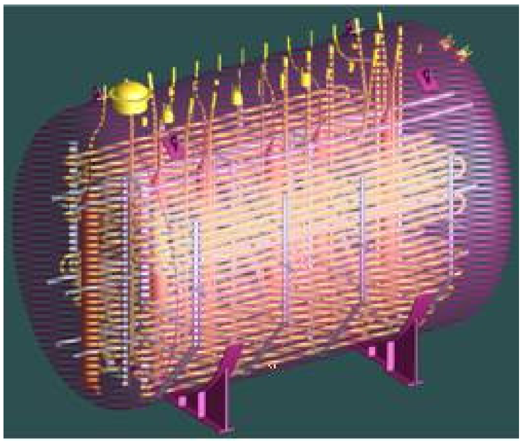


Figure 12: HLLW tank in the LAVA

Techniques for dismantling the HLLW storage tanks

Like the MLLW tanks in the HWL, all tanks will be dismantled remotely. As specified during the licensing procedure, only mechanical and no thermal dismantling techniques will be applied. As a result, aerosol formation will be minimized when cutting the tank structures.

The tools and devices to be used for dismantling partly had to be specially developed and designed for this purpose (no tools were available on the market for the mechanical cutting of stainless steel sheets with a thickness of more than 10 mm).

These tools and devices were tested and qualified in a specially designed test field. As basic device, a so-called manipulator carrier system (see Figure 13) will be applied. Both a manipulator system and a number of other large devices (e.g. hydraulic chisel, hydraulic concrete mill, etc.) may be attached to this carrier system. The manipulator system operates further tools for tank dismantling, e.g. hydraulic thick sheet metal nibblers, compass saws, cut-off saws, etc. According to the current concept, it is planned to dismantle the tanks in the cells to pieces fitting into 200 l drums, to remove these pieces via the HWL-annex south, and to transfer them to the HDB-facilities (waste treatment of WAK department) for further treatment.

Figure 13: Manipulator carrier system in the HWL-Annex South

SUMMARY

Extensive know how and experience of reactor and fuel cycle facilities decommissioning and dismantling is being concentrated since middle of 2009 under WAK management.

The details of the decommissioning and specifically of the remote dismantling of the MZFR, KNK and HLLW-facilities at the WAK site represent a great challenge concerning planning and execution of the various measures as well as concerning the management of the radioactive waste.

Most of the problems are actually being solved technically. In detail:

- The remote dismantling of reactor components and vessels, biological shielding and sodium containing components is a proven technology.
- The planning and licensing for the dismantling of the HLLW-tanks has reached an advanced stage with the license being expected in the near future. The dismantling activities will subsequently start at the end of VEK vitrification operation in 2010.
- The equipment and the tools for the remote controlled dismantling of the HLLW tanks have been tested on mock-ups in a test field and are already in operation on the dismantling of the MLLW-tanks.
- The clarification of the treatment of the residues in the HLLW tanks has been initiated and the removal of the residues will not affect the dismantling activities. Currently the intermediate storage of the waste in the HDB-facilities is provided.

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