DECOMMISSIONING OF THE REACTOR VESSEL OF THE COMPACT SODIUM COOLED NUCLEAR REACTOR FACILITY (KNK)

J. Benkert, F. Willman
Westinghouse Electric Germany GmbH
Mannheim / D

K. Brockmann, I. Hillebrand
Research Center Karlsruhe GmbH
Karlsruhe / D

ABSTRACT

The compact sodium-cooled nuclear reactor facility (KNK) was an experimental nuclear power station with 20 MW electric power situated on the premises of the Karlsruhe Research Center. Initially, between 1971 and 1974, the plant was operated with a thermal core and referred to as KNK I. Later, between 1977 and 1991, it was run with a fast core as KNK II fast breeder power plant. The reactor is to be decommissioned completely down to green field conditions following ten permission steps. The current permission step nine covers the decommissioning of the reactor vessel including its internals.

Because of still existing sodium contamination within the reactor vessel and radioactivity due to exposure to fast neutrons all decommissioning work has to be done remote controlled under nitrogen atmosphere. This requires to erect an enclosure (approx. 530 Mg of steel, wall thickness up to 350 mm, special venting system with nitrogen) above the reactor vessel within the reactor building prior to the start of the disassembly work. The enclosure contains all equipment necessary to cut the vessel into pieces. It also contains all handling manipulators / hoists that the cut-off pieces can be put into drums (capacity approx.150 l).

The drums filled with contaminated pieces can be transported to a sodium washing plant for removal of the sodium contamination.

The washing process for one lot consisting of five drums takes about one week. After completion of the washing process the drums will be sent to the Central Decontamination Plants Department (HDB) which is also located on the premises of the Karlsruhe Research Center.

Disassembling and washing are separate tasks. In order to work independently from each other an intermediate buffer store has been erected where up to fifty drums can be stored. Special shielded transportation devices (shielding bell, shielded transport containers, shielding approx. 20 Mg steel each) are necessary for transportation of the drums between the different locations.

The status of the project is that the enclosure and all equipment has been developed, manufactured and installed on site. The equipment has passed extensive cold and hot start-up procedures. The team to operate the systems has been trained. The dismantling of the reactor vessel has begun. It is estimated that the dismantling of the reactor vessel will take about 12 to 15 months.

INTRODUCTION

The compact sodium-cooled nuclear reactor (KNK) was an experimental nuclear power station with 20 MW electric power. The plant was operated with a thermal core between 1971 and 1974 referred as KNK I. Between 1977 and 1991, it was run with a fast core as KNK II fast breeder power plant.
Due to the exposure to fast neutrons, the reactor vessel and its internals have become highly activated (maximum dose rate in 2002: 27 Sv/h, maximum Co-60 activation in the order of 10^7 – 10^8 Bq/g) and therefore they have to be disassembled using remote techniques exclusively.

The reactor vessel still contains sodium residues (a total of approx. 30 l is to be expected), therefore no wet or thermal cutting techniques can be used. The entire disassembly process has to be carried out under a dry nitrogen atmosphere to avoid reactions between sodium, oxygen or humidity / water.

Manufacture, assembly, cold start-up and hot start-up of the entire equipment including training of the necessary personnel are completed. The status of the following main activities will be presented below:

- Concept of disassembling
- Layout and installation of the enclosure equipped with various remote handling systems and hoists
- Layout, installation and set-up of the disassembly manipulator and its modules / tools including the mock-up for testing
- Modification of the former moderator store into an intermediate buffer store for dismantled parts contaminated with sodium
- Modification of an existing sodium washing plant such that disassembled sodium contaminated parts can be washed
- Layout and manufacturing of a shielding bell for transports within KNK
- Modification of type-II Konrad containers for transports to the Central Decontamination Plants Department (HDB) of the Karlsruhe Research Center
- Summary and outlook

Concept

The concept [1], [2] is to cut the reactor vessel remote controlled into pieces, place them into drums (volume 150 l), clean them from sodium contamination if necessary and prepare them for storage.

Components to be Disassembled

The reactor vessel consists of mayor components as listed in table 1. Except of the outer vessel, all parts have had been in contact with sodium and may be still contaminated with it. The total mass of the reactor vessel is about 43 Mg of steel.

Table I. Components of the reactor vessel and its internals

Component	Height (mm)	Thickness (mm)	Mass (Mg)	Co–60 Activation (Bq/g)
Reflector	2,310	70-170	11.8	3.1 E+7
Thermal shield	2,310	80	7.8	4.8 E+6
Thermal shock baffle	6,500	12	3.8	4.2 E+6
Internals	-	-	2.8	1.2 E+9
Inner vessel	10,500	16	11.8	4.0 E+6
Outer vessel	9,500	12	4.8	2.2 E+6
		Total	**42.8**	

Figure 1 shows structure of the reactor vessel and its internals (left). Furthermore the principal layout of the disassembly manipulator is shown positioned inside the reactor vessel (right).
The sequence of cutting steps is to dismantle the internals from the center to the outer diameter. The inner reactor vessel will be disassembled from the top side down to the bottom. All these parts have been in contact with sodium during operation and will be contaminated with sodium, even gaps between the different components still may be filled with sodium. This may have the effect that those pieces are “glowed” together and need special treatment for dismantling.

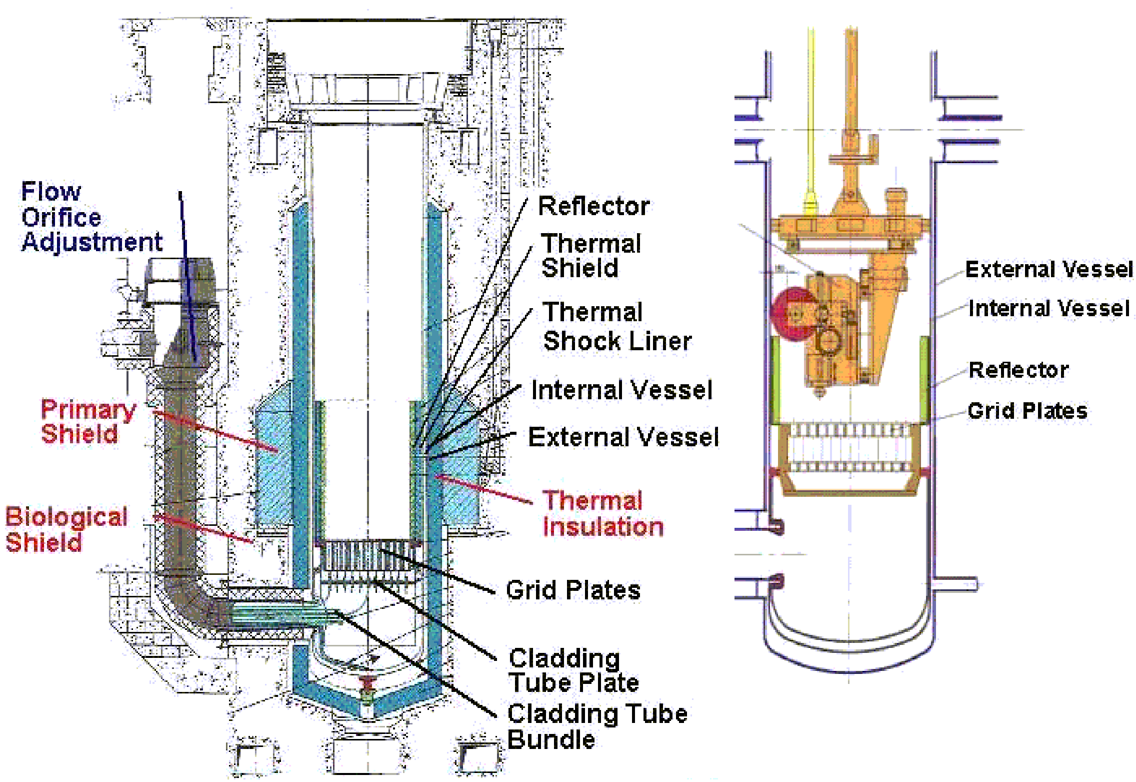

Fig. 1. Reactor (left) and schematic view of the disassembly manipulator (right)

The outer vessel will be dismantled from the bottom up to the top because it is suspended at the top flange. The outer reactor vessel never has had been in contact with sodium, therefore no

washing of the cut pieces is necessary. (Remark: The flow orifice adjustment system except the cladding tube bundle has been disassembled already in the meantime)
A detailed disassembly plan has been developed to cut the reactor into pieces which can be placed into 150 l drums. This plan contains piece identification, position coordinates for the disassembly manipulator within the vessel, machining parameters (e.g. revolutions / minute, feed / minute, length of cuts, expected cutting times, expected amount of chips etc), tools and cutting module to be used.
It is foreseen that all pieces will be transported up to the floor level inside the enclosure by using the disassembly manipulator itself and will be placed into a transfer position. From there a heavy load manipulator is available to pick them up and put them into the drums. At that very time a visual inspection via TV or through a lead glass window is possible to verify that washing is necessary. This detailed planning / procedures contain also instruction on how to place the pieces into the drums. Target is to pack as compact as possible to consume as less as possible necessary expansive final storage capacity.
These detailed procedures shall enable the operators to fully concentrate on a save cutting process and prevent from experiments during the normal operation.

Transportation Logistics

Figure 2 shows the floor level of the reactor building and the auxiliary building. There are two main processes of treatment after having filled a drum with cut pieces.

Drums Filled with Sodium Contaminated Pieces

The above-mentioned filled drums are picked up by a loading crane and transported to a transfer position inside the enclosure. From there the drum can be pulled into a shielding bell which is positioned outside the enclosure on top of it. Then the shielding bell transports the drum from the reactor containment to the buffer storage located in auxiliary building for intermediate storage. The buffer storage has a capacity for fifty drums.

The sodium washing plant can handle five baskets at a time. Transportation from the buffer storage to the washing device is done by the shielding bell too. When the washing process is completed the drums will be returned to the enclosure within the shielding bell again. Through the double-lid lock of the enclosure the drum is put into a 200 l drum which is positioned in a shielded transportation container. After closing the 200 l drum and the transportation container the drum will be transported from the reactor containment to the transport hall located in auxiliary building and from there to the Central Decontamination Plants Department (HDB) for final treatment.

Drums Filled with Sodium Free Pieces

Drums which contain sodium free pieces can be directly transported to the HDB. This will be done such that the filled drums will be put by the loading crane into to the 200 l drums directly and then transported to the HDB as described above.

It is expected that the reactor vessel and its internals can be packed into about 150 drums. In addition the chips of cutting process are to be collected in special drums using a special vacuum system. These drums will be compressed in the HDB in order to reduce their necessary storage volume.

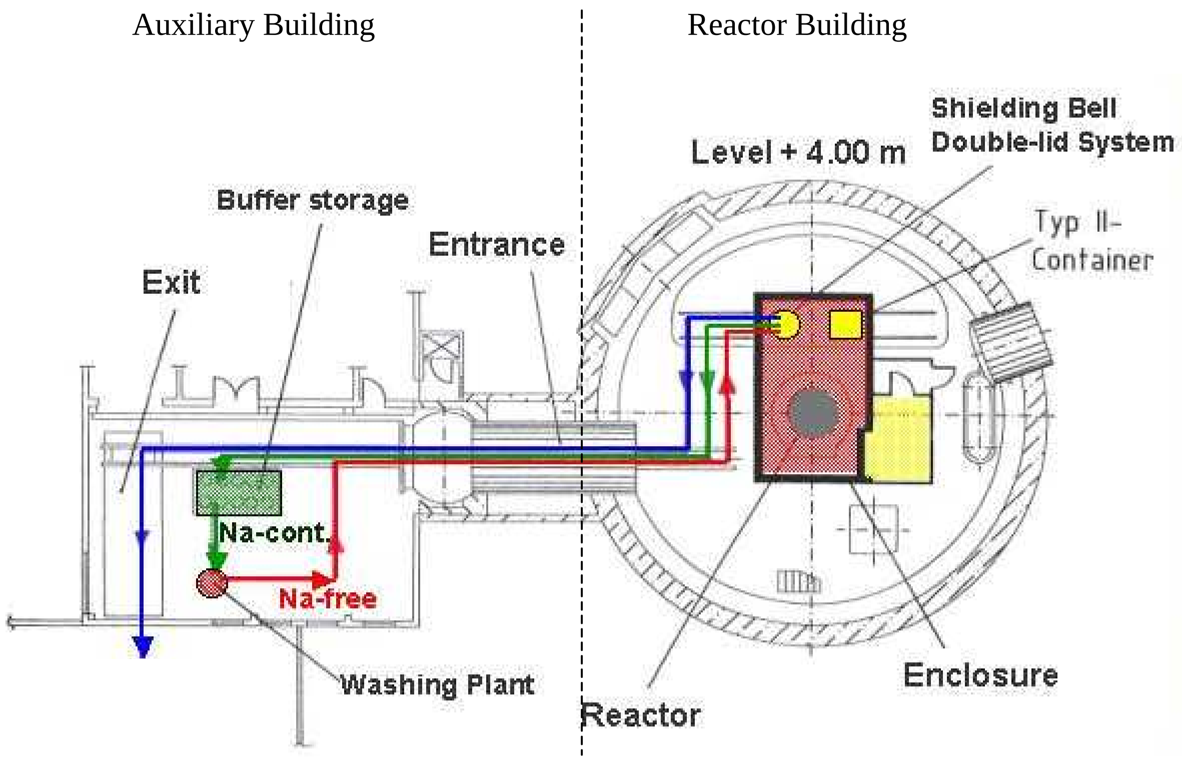

Fig. 2. Floor plan containing enclosure, buffer store, and washing plant

Enclosure and Remote Handling Equipment

Prior to the start of the disassembling work an enclosure has been built on the containment floor level above the reactor vessel. The enclosure is erected out of steel shielding walls consisting of several layers, wall thickness in total from 150 mm up to 350 mm. The shielding has been dimensioned such that the maximum dose rate is less than 5 µSv/h at the outside of the enclosure while the highest activated pieces (reflector / grid plates) are handled on the floor level inside the enclosure. The total mass of the enclosure is about 530 Mg. The enclosure is divided into a handling cell and an intervention cell. Both rooms are separated by a 350 mm thick sliding shielding door.
The inner side of the enclosure is covered with a steel liner for contamination protection and decontamination reasons as well as for sealing purposes. Special attention has been paid to tighten the enclosure and their unavoidable penetrations. This was necessary to reach clean and dry nitrogen atmosphere with a very low oxygen level (< 2.5 %) inside the reactor vessel / enclosure during the disassembling process.

The handling cell contains all equipment to carry out the disassembling work.
- A bridge crane with a main hoist of 6.3 Mg to handle the disassembly manipulator and two additional chain hoists of 3.2 Mg (multi purpose) and 10 Mg (to lift the reactor vessel head).
- Two Master-slave manipulators (change tools and modules)

- A heavy load manipulator (to put the cutted pieces from the transfer position into the drums)
- A loading crane (to lift the filled drums to the position where they can be pulled into the shielding bell or directly put into the 200 l drums)
- A double-lid lock (to transfer the drums from inside the enclosure into the transport containers)
- A lead glass window (to observe processes inside the handling cell directly)
- Video cameras, audio system and illuminating devices (to observe and control all processes including cutting inside the reactor vessel and chip collection)
- A vacuum cleaner (to collect the chips of the cutting process)

The intervention cell contains all equipment necessary to maintain and repair the disassembly manipulator

- Two Master-slave manipulators (to support maintenance / repair)
- A crane (to lift modules and spare parts)
- A lead glass window (to observe the maintenance and repair work)
- Video cameras and illuminating devices (to observe the maintenance and repair work)

A platform car is available which can transport the disassembly manipulator or other equipment between the two cells.
Another cell in front of the intervention cell functions as a personnel transit lock, in case that the intervention cell or the handling cell has to be entered by personnel.
The venting system inside the enclosure is based on nitrogen atmosphere (under partial vacuum condition) to prevent sodium from reaction with oxygen and humidity.

Disassembly Manipulator

The disassembly manipulator is the most important tool for carrying out the cutting and the transportation of the cutted pieces from the cutting location inside the reactor vessel up to the transfer position on the floor level inside the enclosure. It also can carry a vacuum system to collect all chips generated during the disassembly processes.
Figure 3 shows the disassembly manipulator inside the handling cell connected to 6.3 Mg cell crane of the bridge. The disassembly manipulator can be positioned at any position inside the reactor vessel. Cooling of the working area and of the manipulator is done by nitrogen also.
The disassembly manipulator can be tensioned to the reactor wall with eight struts. The tool sled can be equipped with different modules (a total of 15 is available) especially designed to meet the needs for different cutting requirements of the vessel and its internals. Most disassembling will be done by milling using especially designed milling tools. The disassembly manipulator is equipped with several high-dose cameras and an audio system to control the cutting process.
Major efforts were necessary to develop specific modules, milling tools as well as a vacuum system and a digger system to pick-up the milling chips.

The functionality of the disassembly manipulator and all cutting processes as well as the chip collection have been tested extensively in a mock up using / verifying also the procedures described above. The tests have been carried by the later operators as part of their training. The mock-up has modelled all typical internals and geometries / diameters in 1:1 scale, only the height of the vessel has been reduced from 10 m down to 4 m. The mock-up has been installed at the location of the manufacturer of the disassembly manipulator. Also the cell crane, heavy load manipulator and master-slave manipulators have been put in that location to simulate the later conditions of the real reactor. The acceptance tests have been carried out in presence of the customer KNK and the German Technical Inspectorate (TÜV) as part of the licensing process. The duration of tests was about 14 months.

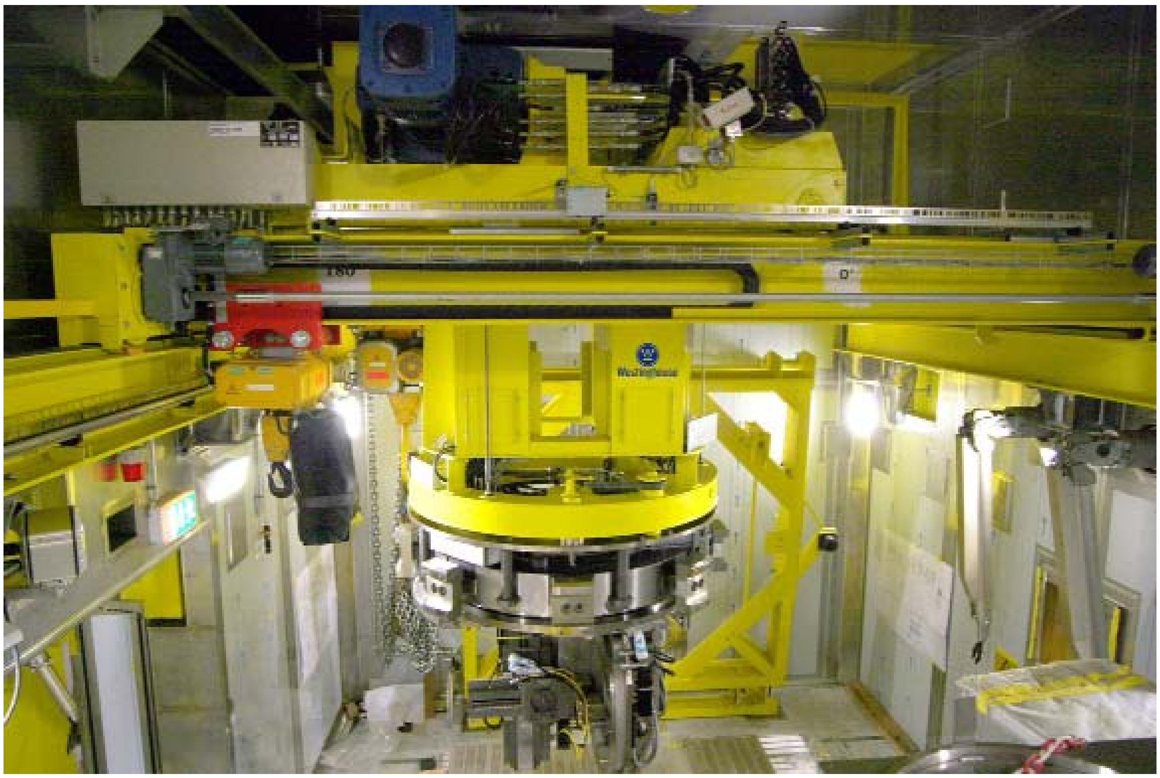

Fig. 3. Disassembly manipulator connected to the cell crane inside the enclosure

Buffer Store

Cutting and washing are independent processes. One to two drums filled with cutted pieces can be expected per day. The capacity of the sodium washing plant is five drums per week. Therefore the former moderator store has been upgraded to serve as a store to buffer up to fifty drums in ten setting positions. Each setting position is closed with a removable plug. A special lid system prevents that the drums will get contact with air during the loading / de-loading process and that no air can penetrate into the buffer during the necessary removal process of the plugs.
The store itself contains also nitrogen atmosphere under low vacuum conditions to prevent reactions of the sodium contaminated pieces with oxygen and humidity. Loading / de-loading of the store with the drums will be done by using the shielding bell.

Washing Plant

During the former operation of the KNK II there was available a washing plant to clean sodium contaminated pieces. Essentially this device was a cylindrical pressure vessel approx. 7 m high in which the sodium is first molten by hot nitrogen and then gradually converted into caustic soda solution by the addition of water vapour. At the end of the process, the entire vessel is flooded with water, drained, and dried with hot air.
The existing washing plant has had to be modified such, that five drums filled with sodium contaminated pieces can be put into the pressure vessel. The upper part of the pressure vessel has been modified that it can be loaded / de-loaded with the shielding bell using a remote controlled double lid system. Also the shielding has been enhanced around the entire washing plant due to the high level of activity contained in the drums. Figure 4 shows a view of the upper part of the washing plant.

Fig. 4. Upper part of the washing plant (drum on the right)

Shielding Bell

A shielding bell has been designed and manufactured to transport the drums from the enclosure in the reactor containment to the buffer store, from there to the washing plant in the auxiliary building and then back to the enclosure. The drums will be pulled into the shielding bell by using a three cable grab system. The wall thickness of the steel wall again is 350 mm to reduce the maximum dose rate down to 5 µSv/h. The mass of the shielding bell is about 20 Mg. A

standardized lid system between all docking locations (buffer, washing plant, enclosure) and the shielding bell allows that the nitrogen atmosphere can be maintained all the time.
The transport logistic is such that the shielding bell will be lowered from the top of the enclosure (6m height) to the floor level and will be put on a transfer car which transports it from the reactor containment to the auxiliary building. There it will be pick-up by the hall crane and lifted on top of the buffer store respectively on the washing plant. To return the drums to the enclosure, the reverse procedure will be carried out.
Because of the theoretical risk that the bell can drop from the top of the enclosure down to the inflexible floor level it has been designed such that its integrity is ensured in that case. Figure 5 shows the shielding bell (left) and the plug removal device (back right).

Fig. 5. Shielding bell (left) and plug removal device (back right)

Transport Containers

Standard type II KONRAD containers have been modified for transportation of the filled drums from the enclosure to the HDB. There has been placed a cylindrical steel shielding (again 350 mm thickness) inside the container. The space between the cylinder and the container has been filled with concrete to have a solid connection. There is a lifting device inside the cylindrical shielding. A 200 l drum can be put into the inner diameter of that cylinder. Into the 200 l drum the 150 l drum filled with cutted (and cleaned) pieces can be placed. The 200 l drum can be closed by a lid. On top of the cylindrical steel shielding a 350 mm thick steel lid will be placed for shielding reasons too.

The principal transport logistic is such that the container contains a closed 200 l drum at the beginning of the transport process where inside the 200 l drum an empty 150 l drum is positioned. The top of container is covered by a thin steel lid which will be removed manually. At the entrance of the enclosure there is a device to remotely remove the lid from the cylindrical shielding. Having completed this, the container will be moved below the double-lid lock of the enclosure (see figure 6). The 200 l drum will be lifted and pressed against the double-lid lock. After verification of tight connection the lock opens and the loading crane picks up the empty 150 l drum out of the 200 l drum and lifts it to a position inside the enclosure. Then a filled 150 l drum will be put back into the 200 l drum and the double lid lock has to be closed. The 200 l drum inside the container will be lowered. The container moves back to that position where the shielding lid can be put on again. Finally the thin steel sheet lid will be put on top of the container. Now the container is ready for transportation to the HDB. Five of those containers are available for smooth circulation of the drums.

Fig. 6. Transport container below the double-lid lock of the enclosure

SUMMARY AND OUTLOOK

All equipment has been manufactured and installed on-site. The team to carry out the disassembly and transportation work has been trained and is available. Cold start-up and hot start-up has been completed successfully. The reactor has been opened by lifting the reactor vessel head. The disassembly work has begun. It is expected to complete this task within 12 to 15 months.

REFERENCES

1. I. Hillebrand, J. Benkert, Concept for Dismantling the Reactor Vessel and the Biological Shield of the Compact Sodium-Cooled Nuclear Reactor Facility (KNK), WM ’02 Conference Feb 24-28 2002 Tucson AZ
2. I. Hillebrand, J. Benkert, Installation of Remote Handling Systems for Demolishing the Reactor Vessel of the Compact Sodium–cooled Nuclear Reactor (KNK), Annual Meeting on Nuclear Technology 2004, Duesseldorf Germany