ABSTRACT

The Multi-purpose Research Reactor was a pressurized-water reactor cooled and moderated with heavy water. It was built from 1961 to 1966 and went critical for the first time on 29 September 1965. After nineteen years of successful operation, the reactor was de-activated on 3 May 1984. The reactor had a thermal output of 200 MW and an electrical output of 50 MW.

The MZFR not only served to supply electrical power, but also as a test bed for:
- research into various materials for reactor building (e.g. zirkaloy),
- the manufacturing and operating industry to gain experience in erection and operation,
- training scientific and technical reactor staff, and

The experience gained in operating the MZFR was very helpful for the development and operation of power reactors.

At first, safe containment and enclosure of the plant was planned, but then it was decided to dismantle the plant completely, step by step, in view of the clear advantages of this approach. The decommissioning concept for the complete elimination of the plant down to a green-field site provides for eight steps. A separate decommissioning license is required for each step.

As part of the dismantling, about 72,000 Mg [metric tons] of concrete and 7,200 Mg of metal (400 Mg RPV) must be removed. About 700 Mg of concrete (500 Mg biological shield) and 1300 Mg of metal must be classified as radioactive waste.

EIGHT INDIVIDUAL STEPS (LICENSES) DOWN TO THE GREEN FIELD

Each dismantling step is accomplished according to pre-approved work schedules. Adherence to the approved dismantling steps is controlled by the supervisory agency on behalf of the licensing authority. Furthermore, the supervisory authority encharges an expert (Technischer Überwachungsverein, TÜV) with the verification of the documentation, assessment of the dismantling techniques planned to be used, and control of the major dismantling steps directly on site, on the average once per week. At the end of each partial decommissioning license, the MZFR has to prove that the dismantling objective has been reached.
Table I: 8 steps down to the green field

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
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<tbody>
<tr>
<td>1st + 2nd steps</td>
<td>Shutdown of individual installations; preparing work for dismantling; modifying of the systems; disposal of the D2O; drying of the plant areas</td>
</tr>
<tr>
<td>3rd step</td>
<td>Demolition of the cooling towers, emptying the turbine hall</td>
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<tr>
<td>4th step</td>
<td>Chemical decontamination of the primary systems, dismantling of reactor auxiliary systems in the auxiliary building</td>
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<tr>
<td>5th step</td>
<td>Dismantling of security facilities on the MZFR site</td>
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<tr>
<td>6th step</td>
<td>Dismantling of the primary systems and all reactor auxiliaries in the reactor building (e.g. steam generators, pressurizer)</td>
</tr>
<tr>
<td>7th step</td>
<td>Dismantling of the RPV and its internals</td>
</tr>
<tr>
<td>8th step</td>
<td>Dismantling of the biological shield; decontamination of all buildings and clearance measurements of the site; demolition of the buildings</td>
</tr>
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</table>

Steps 1 to 6 have already been finished. Step 7 started in December 1999. The application documents for step 8 were submitted to the licensing authority in December 2000, the revision is underway.

7th DECOMMISSIONING STEP: DISMANTLING THE RPV

The performance of the dismantling work under the seventh step of decommissioning is in the hands of one contractor. Checking and approving of the implementation plans and quality assurance as well as monitoring of the results of the work are done by the Karlsruhe Research Center.

The dismantling work must be done on site, the dismantling concept is to work from top to bottom and from inside to outside.

The dismantling concept provides for the following main stages (see Figure 1):

- **Stage 7.1**: Removal of the components above the RPV (a) and removal of the rod-shaped components within the RPV (b)
- **Stage 7.2**: Dry dismantling, parts 1 (RPV lid) and 2 (upper spacer and its weight ring)
- **Stage 7.3**: Underwater dismantling (plasma cutting of the moderator tank and of the thermal shield)
- **Stage 7.4**: Dry dismantling, part 3 (oxy-acetylene cutting of the reactor pressure vessel) and clearing the building site

The dismantling work of the RPV will be done by the following main techniques:

- For dry dismantling of the RPV lid and the upper and lower spacers, a band saw and a dismantling table have been installed;
- For underwater dismantling, flame-cutting gases that are mixtures of N2, H2, and Ar are used for the plasma torch, in addition mechanical techniques will be employed;
- For dry dismantling of the reactor pressure vessel, an oxy-acetylene flame cutter will be applied. The RPV will be cut into 4 segments. Each of them will be transported to the dismantling table and dismantled by the band saw.

All dismantled parts will be packed into repository casks at a packing station. The packing station provided for this purpose, along with its refueling machine crane, the loading container, the cask closing container, and the transportation system, has been installed.

The repository casks will be transferred to the Central Decontamination Department (HDB) for disposal.

The situation of today (December 2002) is the following:
The rod-shaped components above and inside the RPV have been dismantled and disposed of:
about 315 single components with a total mass of 27 Mg and an integral activity of 100 TBq;
All fabrication work for dry dismantling parts 1 and 2 has been done, the trials are finished.
The RPV lid has been dismantled and disposed of.
The dismantling of the upper spacer is in preparation.
The equipment for underwater dismantling has been installed on a test bed, many tests with the plasma torch have been completed successfully, additional tests are in preparation.

7th Decommissioning Step,
Stage 1: Removal of the Rod-shaped Components

The rod-shaped components above and within the RPV were dismantled by hands-on techniques and disposed of. After the removal of the rod-shaped components, the equipment used for this purpose was dismantled, decontaminated, and transferred to the HDB for disposal.

In order to determine the radiological situation in the RPV, the dose rate was measured at various positions and at various heights. The heights given start from the top edge of the RPV nozzle and reach almost down to the bottom of the moderator tank. The highest dose rate was 7 Sv/h in the middle of the core. Ten years ago, 30 Sv/h was measured in the middle of the core, with the rod-shaped components still installed.

This stage was started in December 1999 and completed in September 2000.

Further information about the dismantling of the rod-shaped components, including the planning, fabrication, and implementation can be found in [1].

7th Decommissioning Step,
Stage 2: Dismantling of the RPV Lid, the Upper Spacer, and the Spacer Ring (Dry Dismantling Parts 1 and 2)

This stage focuses on the dismantling of the upper parts of the RPV. Before the dismantling of the RPV lid could be started, the following work had to be done:
- removing of the concrete shielding blocks located in the annulus;
- removing of the upper part of the RPV insulation;
- manual dismantling of the 72 RPV stud bolts;
- cutting off the nozzles located at the edge of the RPV lid (33 pieces)
- parting of the weldable seal membrane between the RPV lid and the RPV body with a weldable-membrane parting device.

After the RPV lid had been lifted off and transported to the dismantling table, a ring, called the “reflood compensator” was mounted on the flange of the RPV body, so that the demineralized water level - as a radiation shield - inside the RPV could be raised by about two meters.

Then, the components
- the upper spacer, a filler piece to reduce the dose rate to the top, and
- the spacer ring, a component to take off the weight of the upper spacer,
were dismantled.

The divided parts were transported to a packing station with crane-mounted grabs, and packed into shielded casks. The dismantling and packing of the RPV lid, upper spacer, and spacer ring was done by remote control. Table II gives an overview of the mass and activities of the components.
Table II: Mass and activity of the components to be dismantled in stages 1 and 2 dry dismantling

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass [Mg]</th>
<th>Activity (Co-60)</th>
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<tbody>
<tr>
<td>RPV lid</td>
<td>67.6 (ferritic steel with an austenitic cladding)</td>
<td>5 E 08 Bq</td>
</tr>
<tr>
<td>Upper spacer</td>
<td>52.5 (ferritic steel with an austenitic cladding)</td>
<td>5 E 12 Bq</td>
</tr>
<tr>
<td>Spacer ring</td>
<td>13.3 (austenitic steel)</td>
<td>5 E 12 Bq</td>
</tr>
</tbody>
</table>

All the equipment required for the second stage of dismantling was installed and put into operation in accordance with the commissioning programs. All the equipment installed for the remote removal of the reactor pressure vessel is operated from a control console outside of the controlled area.

The main equipment for the parts 1 and 2 of dry dismantling can be seen in Fig. 2.

This equipment consists of:
- band saw;
- dismantling table;
- manipulator support system;
- chip exhauster system;
- transfer table;
- crane-mounted grabs;
- packing station,
- intervention area

and has been installed in an additional containment with an additional supplementary ventilation system (2 x 6000 m³/h). A dismantling area in the reactor compartment, an intervention area, and the packing station have been set up in the reactor building on the level +10/11 m.

The components will be placed on the dismantling table by means of the reactor circular crane or the refueling machine crane. The band saw that traverses on rails will be used to cut the components into pieces that can be handled. The cut-off pieces will be deposited on the transfer table by means of grabs hanging from the refueling machine crane and transported with the table into the packing station.

Further handling of the cut pieces will be done in the packing station. This station consists of the loading freight container and refueling machine crane, the closure container, the rails and traversing carriage, and two working platforms.

The cut pieces will be lifted from the transfer table and loaded into shielding casks using the refueling machine crane. Before this, the covers will be lifted off the shielding casks in the closure container and the shielding casks will be positioned under the corresponding loading opening in the loading container by means of the traversing carriage. The packaging processes there will be carried out under remote control and monitored with cameras.

After loading, the covers will be placed onto the shielding casks again and bolted down in the closure container. Next, the shielding casks will be set down on the 0-m level with the circular reactor crane. From there, they will be transferred to the outside and transported to the Central Decontamination Department.

In the intervention area with the shielding door, intervention area band saw, and the decontamination box and intervention crane, repairs of the band saw will be carried out. For interventions, the shielding door will be closed, so as to shield the dismantling area against the radiation.

Planning, fabricating, and commissioning of the equipment have been completed. Factory acceptance testing of the band saw and the dismantling table has taken place, and the many saw cuts of workpieces with a thickness of up to
1400 mm have been performed successfully. Following testing, the trial and training program was carried out, and after a few faults had been corrected, the authorities gave the permission to start the dismantling activities.

**Training, Trials, Demonstration, and Implementation**

In autumn 2000, the implementation started with the unscrewing of the 72 RPV stud bolts and was completed successfully.

After that, all concrete shielding blocks located in the annulus were removed, so that a circular runway could be installed there. Each concrete shielding block weighed about 300 kg. The circular runway will be used for the following stages: A bridge manipulator (underwater dismantling) and later a supporting and rotating ring (dry dismantling part 3) will be mounted on this circular runway for the subsequent stages of dismantling. The annulus around the RPV between the RPV and the biological shield was cleared, and the circular runway was installed.

Next, the RPV insulation was removed. This insulation consisted of numerous sheet-metal case bays filled with rock wool. Afterwards, the equipment for performing parts 1 and 2 of dry dismantling was installed. Installation of this equipment of band saw, transfer table, and dismantling table in the reactor compartment began in December 2000. On the dismantling table, the components to be parted will be fed into the band saw appropriately for making notching cuts.

Then, internal commissioning of systems began. The audio and video installations were also added and modified for parts 1 and 2 of dry dismantling.

Next, the grabs for the refueling machine crane and the loading crane were delivered.

After that, the cutting off of the RPV nozzles started. The nozzles located at the edge of the RPV lid (33 pieces) had to be cut off to permit optimal loading of the casks. This was done by means of a circular cutting device operated by compressed air.

Between the body of the RPV and the RPV lid, there was a weldable seal membrane. This weldable seal membrane had to be parted by means of a parting device for weldable seal membranes before the lid was lifted off.

This parting device consisted of a rail-guided abrasive cut-off wheel that parted the seal over a length of about two meters within a housing. The parting device had to be repositioned seven times. The housing was connected to the auxiliary ventilation system in order to prevent the spread of contamination by grit from the start.

A function test with a parting trial was conducted in the ‘Cold Workshop’ in the presence of the independent expert. In order to determine whether there was any tritium remaining within the weldable seal membrane, four holes were drilled and air was extracted from the weldable seal membrane before parting. Thus, it could be demonstrated that there was no tritium present.

While the circular cutting off of the nozzles was interrupted, the weldable seal membrane was parted.

After the commissioning (together with the expert TÜV) of the equipment (except for the manipulator support system, the manipulator, and the chip exhauster system), the personnel was instructed in the operation of the equipment and trained, and interaction of the equipment was tried out. The sequence of disassembly, packing, handling, and transportation work was listed in detail in a trials program, checked by the independent expert, and then demonstrated to the supervisory authority step by step on site. The trials program included:

- Transport of Mosaic casks (only for the higher-activated parts of the moderator tank and the thermal shield) and steel casks into and out of the packing station;
- Handling of the casks within the packing station and the removal and placement of covers;
- Sawing tests on a dummy, with lengthwise and notching cuts;
- Handling, packing, and transportation of sawn dummy parts with the respective grabs.

The faults discovered were recorded and subsequently corrected. The repeated demonstration of the equipment included the manipulator support system, the manipulator, and the chip exhauster system.

When the RPV components are sawed, chips are created, which are partly collected in a drum by means of a conveyor system built into the band saw. But a large portion of the chips remains on the dismantling table or falls onto the floor. In the course of sawing operations, these chips which can have specific activities up to $4 \times 10^4$ Bq/g (Co$^{60}$)
would become an ever greater source of radiation, thus providing a cumulative local dose rate of several mSv. In order to prevent this, a chip exhauster system with an output of about 4 kW has been installed in the loading container, having a 15m long hose with a suction nozzle. This suction nozzle is guided by a hydraulically powered master-slave manipulator (with unilateral position control and six degrees of freedom).

In order to reach both the floor and the dismantling table to extract the chips, the manipulator is mounted on a manipulator support system with four independent modes of movement (bridge traversing, trolley traversing, lifting motion, rotary motion). The chips sucked up are conveyed into a collecting vessel that is located in the loading container above the loading hatch. At a defined level of filling, the collecting vessel is swiveled over the open loading hatch and emptied by opening a slide. Then, it is swiveled to the side again.

All the equipment was demonstrated to the independent expert again, and after his consent, further work on dry dismantling, Parts 1 and 2, was done.

**Raising, Transporting, Setting Down, and Dismantling the RPV Lid**

Before lifting the RPV lid off the body of the RPV, a ventilation isolating segment was mounted at the construction opening between the reactor compartment and the upper building level +25 m. Thus, a directed flow of air from the upper building level +25 m into the reactor compartment level + 10/11 m was ensured despite the work carried out with the reactor polar crane.

The RPV lid had been lowered onto the RPV body and bolted in place in 1964, and not lifted off again since then. The lid sat fitted in a machined shoulder of the RPV body, and had a gasket in its seat as well. Because of this situation, the RPV lid, secured to the reactor polar crane, was raised from its seat by means of four hydraulic cylinders, and then transported to the dismantling table by the reactor polar crane. For this, a base structure had been placed on the dismantling table.

This structure consisted of a base plate, onto which the supports are welded, which have to be inserted into the lid’s holes. These supports are intended to hold the sawn-off parts and, thus, ensure that the saw band does not jam.

During the actions for dry disassembly, Parts 1 and 2, the RPV, with the reflood compensator already mounted, was filled with demineralized water.

**Sawing Up the RPV Lid**

The RPV lid was first sawed into pieces weighing up to 2.4 t in accordance with the cutting plan (Figures 3). The cut-up pieces and the support structures cut off from them were transferred out by differing disposal routes:

The cut-off parts were transferred from the sawing table to the transfer table by means of grabs and the refueling machine crane, and transported with it to the packing station. Here, the parts were packed into the casks for ultimate waste disposal with the loading crane by means of magnetic grabs.

Once one of the casks had been loaded completely, its shielding lid was placed on it in the cask-closing container. Then, the cask was withdrawn from the packing station. Further transport to the 0.0-m level was done with the reactor polar crane. Dose rate measurements were performed before and during transportation.

On the 0.0-m level, the cask was placed onto the track-bound carriage, and, after wipe tests had been performed, driven up to the materials lock.

The support structures were sawed up during the sawing process as well. The parts sawed off were driven to the intervention room together with the sawing table and the band saw, after being suctioned clean, and decontaminated in the decontamination box.

Due to the hardening of the material structure resulting from neutron radiation, the saw band’s rate of feed had to be reduced from 4 mm/min to 2.5 mm/min.

In order to reduce the scattering of chips, the saw’s direction of cut was reversed, and the chips were extracted directly at the point of emergence of the saw band above the lid. In this way, the volume of chips could be reduced by up to 10%.
The essential data of dismantling:

- Mass of RPV lid: 67 Mg
- Area of cut edges: 55.63 m²
- Rate of feed: 2.5 mm/min
- Mean sawing time per cut-up piece: 7.3 hours
- Number of cut-up pieces: 52
- Number of ultimate disposal casks: 12
- Max. specific Co60 activity (sampling): 50 Bq/g
- Amount of radioactivity disposed of (Co-60): 1.2E8 Bq

Conversion and Modification of the Cutting-up Equipment for Dry Dismantling, Part 2

On the basis of the insights gained during the dismantling of the RPV lid, the cutting-up equipment was partially modified as part of its conversion for dry dismantling, Part 2 (upper spacer):

- Deflector plates were mounted on the cutting table and the band saw in order to prevent the chips from collecting at unreachable locations.
- The capacity of the chip extraction system was increased by improving its intake capacity and transport.
- The audio and video systems were enlarged in order to improve the view and communications conditions.

Additional Cutting-up Equipment

The local dose rate at the bottom of the upper spacer amounts to about 300 mSv/hr. In order to avoid interventions by the personnel during the withdrawal and setting down of the upper spacer from becoming necessary, two dummies were made for testing the operations (Fig. 4). This also served as an evidence of safe handling for the supervisory authority.

In order to avoid exposure of the personnel to radiation during interventions in the handling equipment, additional shielded intervention capabilities and recovery equipment have been installed.

At present, the new and modified equipment is being tried out, and the personnel is being trained in its use. This will be followed by a demonstration to the supervisory authority.

The dismantling of the upper spacer will begin in December 2002. Afterwards, the spacer ring will also be cut up during dry dismantling, Part 2. A dummy will be made of this beforehand for handling trials, as well.

7th Decommissioning Step,
Stage 3: Dismantling of the Moderator Tank and the Thermal Shield (Underwater Dismantling)

In the third stage of dismantling, the underwater dismantling, the moderator tank and the thermal shield will be dismantled under water by means of a plasma-arc cutting torch and the equipment needed for this.

At present, the tools for plasma cutting are being tested in a test bed. There, experiments on plasma cutting and on handling the cut-up parts will be conducted.

The test bed is set up in a hall with several levels (0.0-m, 2.0-m, and 8.0-m elevations). The supporting and rotary ring, on which the bridge manipulator with its mast and grab is positioned, is located on the 8.0-meter level together with the monitoring, operating, and control equipment, and the electricity supply for the plasma-arc cutting torch.

The central component of this stage of dismantling, the bridge manipulator, consists of a bridge that can travel along a circular runway. A trolley, to which the mast is attached, traverses along the bridge. Two carriages, independent of each other, run along the length of the mast.
On one of them, a seven-axes manipulator (“slave”) is mounted, whose joints are powered by hydraulic actuators. The motions of the joints determined by the master arm are transferred to the manipulator by means of a master-slave control (unilateral position control). This manipulator serves to handle cut-off parts and can also be used for other tasks. The parts cut underwater are placed into a basket which is inserted into the drying unit by means of the refueling machine crane.

The five-axes tool support which directs the plasma torch is mounted on the other carriage. The kinematics of the tool support are controlled by means of a programmable controller. The plasma torch is handled in the automatic mode, with the individual vertices of the tool path being “taught” for this purpose.

The water treatment plant has been installed. Planning of the drying unit for the parts disassembled underwater is completed. It will be tested and qualified in the first quarter of next year.

The first cuts performed with a plasma gas ratio of 1:1:1 (argon, nitrogen, hydrogen) have shown that a good cutting performance can be achieved by this cutting method. However, some parameter variations still need to be investigated in order to achieve optimum results for the respective applications.

We also need to investigate whether all components can be cut up according to the cutting plan with the existing equipment. Furthermore, it turned out that more time than intended must be allowed for the cutting, setting up, and teaching.

The trials of underwater plasma cutting are expected to be completed in the first half of next year, so that underwater dismantling can begin in 2004.

**7th Decommissioning Step,**

**Stage 4: Dismantling of the Lower Spacer and the RPV Body (Dry Dismantling Part 3)**

In the last stage of dismantling, the insulation on the lower part of the RPV will be removed and then the lower part of the RPV will be dismantled into individual segments.

Most of the equipment for the fourth stage of dismantling, the dismantling of the lower spacer and the RPV body, have already been manufactured. The tests can be carried out in mid-2003.

Due to the radiological conditions, some additional equipment, such as working platforms and shielding walls, is required, since the dose rates (according to our present knowledge) in the dismantling area can amount to as much as 3.2 mSv/h when the RPV body is raised. The planning of this equipment has also been completed.

Implementation of dry dismantling, Part 3, is scheduled to start in 2005.

**CONCLUSION**

The dismantling of the RPV represented and still represents a challenging task for the MZFR dismantling team. The seventh dismantling step was divided into four stages. This proved to be very effective, as each stage needs to be executed with different dismantling techniques, due to the varying technical, radiological, and geometrical boundary conditions prevailing. This allows for an execution of the work planned and a parallel testing of subsequent working steps in a test field. At the same time, planning, fabrication, and procuring for the next-but-one step are carried out.

The dismantling techniques to be applied are not new. It was even tried to use established processes which had already proved to be successful. The experience gained from this RPV dismantling with a total activity of about 1E15 Bq under very complex boundary conditions will be very valuable and useful for the future dismantling of power reactors. The focus will be on the underwater dismantling of the moderator tank and the thermal shield, as here large wall thicknesses will have to be cut with the plasma cutting facility.