Gundremmingen KRB-A

Dismantling techniques for activated components

The dismantling of the activated components was executed rernote controlled and under water.

Therefore new techniques and procedures were investigated and qualified. Fig. 1 shows the RPV and internals before starting the decommissioning work.

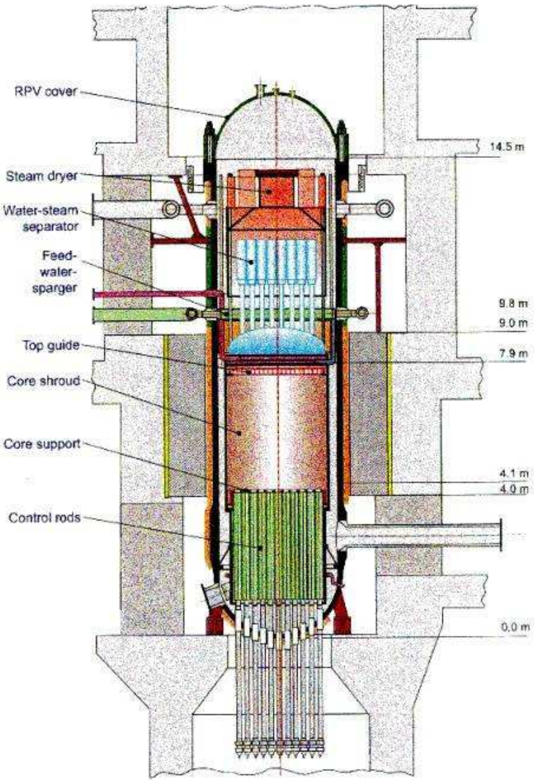

Figure 1. Vertical section of the reactor pressure vessel

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1. Reactor pressure vessel

The cover of the reactor pressure vessel (RPV) was the first activated component which had to be segmented.

It is made out of ferritic material (20 NiMoCr 26) with an inside austenitic cladding (X5 CrNi 18 10) of 7 mm thickness.

The dimensions and further main technical data are given in Table 1.

	Base material	**Cladding**
Wall thickness (flange) (mm)	750	7
Wall thickness (dome) (mm)	80	7
Contamination:		
^{60}Co (Bq/cm^{2})	50 ... 1 200	800 ... 1 600
^{241}Am (Bq/cm^{2})		~ 6
Mass (Mg)	60	
Diameter (mm)	4 180	
Height (mm)	2 360	
Dose rate (contact) (µSv/h)	320	
Dose rate (1 m distance) (µSv/h)	60	

Table 1. Dimensions and technical data of the RPV-cover

Fig. 2 shows the RPV-cover after lifting from the reactor pressure vessel.

Figure 2. The RPV-cover after lifting from the vessel

A detailed investigation was done on the status of contamination and activation of the RPV-cover.

A ^{60}Co-activation of about 1 Bq/g was found in the 7 mm austenitic cladding caused by thermal neutrons during operation of the plant. Also the ferritic base material is activated (0.4 Bq/g ^{60}Co).

Table 2 gives the nuclide vector for the cladding and the base material. The high percentage of ^{63}Ni in the stainless steel cladding corresponds to the high amount of nickel in this alloy.

Nuclide	**Base material**		**Cladding**	
	(%)	(Bq/g)	(%)	(Bq/g)
^{60}Co	12.6	1.5	26.8	21.00
^{55}Fe	68.4	8.1	10.3	7.80
^{63}Ni	18.7	2.2	62.5	49.00
^{241}Am	0.0	0.0	0.1	0.08
Other	0.3	0.0	0.3	0.24
Total		11.8		78.12

Table 2. Nuclide vector and mass-specific activity of the RPV-cover

Due to the fact, that austenitic material can not be cut by using usual flame cutting, inactive thermal cutting tests were executed on cladded material to find out the best cutting technique.

It could be determined, when using a commercial propane-powder torch and starting to cut from the ferritic outside, the process of cutting through the stainless cladding is possible. This is also achievable without adding powder to the propane-powder torch.

Due to the dimensions of the material lock gate between reactor building and turbine house it was necessary to pre-segment the head into five pieces still at the reactor floor. This was done manually by making use of the experiences gained from the inactive tests. Flame torch cutting was performed by two persons wearing protection masks.

Continuous operation of a filtering device under a temporary cutting tent was required.

The pre-segmenting resulted into 5 single pieces. The cutting length was about 21.5 m. The width of the cutting kerf was within the range of 12 to 15 mm.

A cutting velocity of 50 mm/min could be achieved. The consumption of totally 35 aerosol filters during torch cutting was rather high, so that a recleanable filter will be used for similar application in the future.

In view of the dismantling of the reactor pressure vessel, plasma arc cutting, flame cutting and sawing were applied on the cladded RPV-head and compared to get more experience with this material. The main parameters like cutting time, costs, aerosol release and waste quantities for each method were investigated under constant conditions in a special cutting cabin in the turbine house.

During the sawing process no increase of the aerosol concentration was detected. However, thermal cutting techniques resulted in a release of radioactive particles. A test series in the cutting cabin using different thermal cutting techniques at a segment of the RPV-head resulted in the following diagram as shown in Table 3.

Tool	**Nuclides**	**Aerosol activity** (Bq/m^3)	**Cutting speed** (mm/min)
Oxy-Acetylene	^{60}Co	7	120
Oxy-Propane	^{60}Co	10	100
Powder-Oxy-Acetylene	^{60}Co	10	120
Powder-Oxy-Propane	^{60}Co	14	120
Plasma arc (45 mm wall thickness)	^{60}Co	6	130

Table 3. Aerosol generation during thermal cutting

Determining an appropriated cutting technique for the low active sections of the RPV, investigations at the RPV-head revealed that sawing of thick-walled and cladded material is cost-efficient and is restricted only by geometry and dimensions of the component.

Flame cutting was the preferred cutting method for the RPV-head, but can only be accomplished by starting the cut from the ferritic outside of the component and by operation of suck-off filtering devices.

Plasma arc cutting with a hand-held torch reached the technical limit due to the wall thickness.

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2. Segmenting unit ODIN

For segmenting the activated and cylindrical reactor internals remote-controlled underwater cutting techniques had to be investigated.

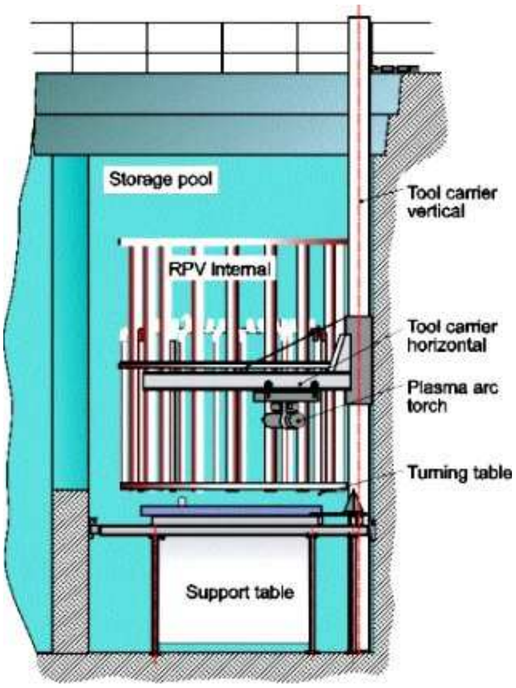

Figure 3. Tool carrier system for handling the plasma arc torch

Different cutting techniques were tested and finally the plasma arc cutting was selected because of:

- no reaction force;
- the small dimensions of the cutting tool; and

- the high performance.

The aerosol generation during plasma arc cutting can be handled by an effective suck off device. For handling the plasma arc torch a tool carrier system was developed and qualified at the University of Hannover and installed in the equipment storage pool (Fig. 3).

The base is a vertical guide of 9 m height with an arm as a horizontal guide. The horizontal guide is 2.5 m long and was bent to a radius of 2 m so the tool can move exactly on the cylindrical reactor internals surface. As a third axle the tool carrier can move 300 mm to the centre of the RPV internal.

To control the cutting the unit is also equipped with underwater light and cameras. An underwater turning table was added to the system so the device can be rotated 360°.

Fig. 4 shows the equipment storage pool with the cutting tool and the suction hood for collecting the radioactive particles above the cutting place during plasma arc cutting.

Figure 4. Underwater plasma arc cutting in operation

3. Underwater handling techniques

Most of the activity inventory of KRB-A is concentrated in the internals of the RPV.

For dismantling of these components the application of reliable remote-controlled and underwater techniques were necessary.

An electrical master-slave manipulator (EMSM) is sometimes useful for the remote-controlled positioning, fixing of lifting equipment and handling of components during the dismantling of the RPV and its internals. Force reflection and force feedback between master and slave arm could be helpful especially during the RPV dismantling for the following tasks:

- positioning of cutting tools;
- changing of wear parts at the cutting tool;
- fixing of internals for transport;
- pick-up and handling of cut-off pieces;
- inspection of the internals with an underwater camera;
- mechanical opening of screws, etc ...

There are different master-slave manipulators for underwater application available on the market.

In order to find the optimal manipulator for KRB-A several manufacturers and service companies of hydraulic and electrical master-slave manipulator have been requested to conduct inactive tests.

First, a test series with different master-slave manipulators had been carried out in operation at the atmosphere. Standard handling operations have been passed by all manipulators in order to check the operating range and the handling possibilities of the slave arm in practical tests (Table 4).

Name	**AKRIBES**	**TITAN 7F**	**EMSM 2C**	**TELBOT**
Manufacturer	Noell/Blocher (D)	Schilling (USA)	Bilz (D)	HWM (D)
Service company for tests	Noell (D)	Ansaldo (I)	ANSA (F)	ANSA (F)
Material	Aluminium/Steel	Titan	Aluminium/Steel	Aluminium/Steel
Mass (Mg)	143	67	150	500
Maximum load (kg)	25	110	24	30 - 240
Arm range (mm)	1 650	1 980	1 400	1 000 - 5 000
Degrees of freedom	6 + grip	6 + grip	6 + grip	6 + grip
Force feedback	1:1, 2:1, 4:1	-	2:1, 20:1	-

Table 4. Technical data of the manipulators

Because of the small design, two master-slave manipulators were selected for further tests: the EMSM 2C, manufactured by Bilz, Ostfildern (D), and the TELBOT, manufactured by HWM, Meersburg (D).

During the test series both manipulators were operated by ANSA, Bouzonville (F).

The further test series have been carried out in the test basin of Versuchs-atomkraftwerk Kahl (VAK). The inner diameter of this water basin at VAK is 3.7 m and is identical to the diameter of the RPV of KRB-A.

This fact made it possible to obtain a realistic impression for the active implementation.

The tests have been carried out with a water depth of 5 m. One slave manipulator was fixed at a crane hook during the tests and one was tested stationary on the floor of the basin.

Fig. 5 shows the VAK test basin with the arrangement of models: on the upper left side is the lower grid plate, on the lower left side is the top guide and on the right side is the model for simulation of tool exchange and fixing of lifting devices.

Fig. 6, 7 and 8 show the control unit with monitors and the master manipulator of the EMSM 2C, and the two manipulators during the handling tests.

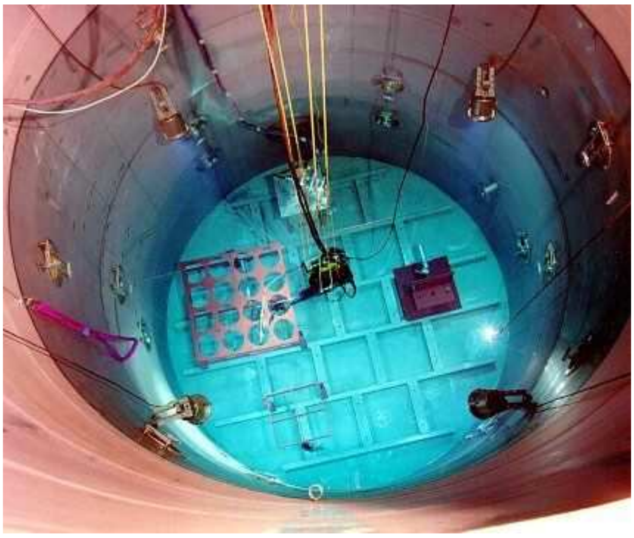

Figure 5. Test basin with arrangement for the EMSM testing

Figure 6. Control unit for the EMSM 2C

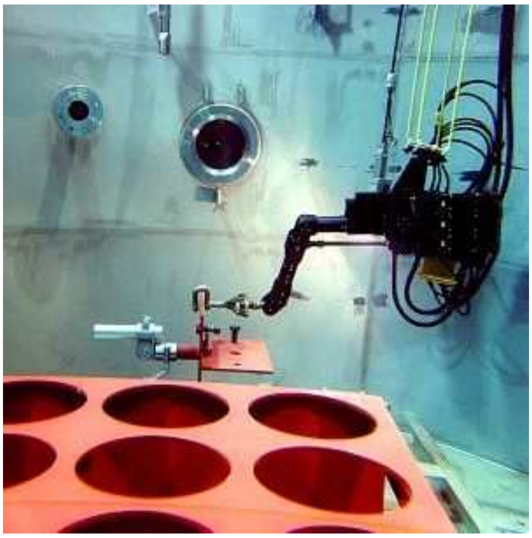

Figure 7. EMSM 2C during fixing a bolt

Figure 8. The slave arm of the TELBOT-manipulator during an unscrewing task

All handling manipulations at different models of RPV-internals have been performed without any problems. During the whole testing period, both slave manipulators proofed to be water resistant.

So both manipulators are suitable for underwater use.

The slave manipulator fixed on the crane hook was easier to position in the test basin. Also during collisions the arm wasn't damaged because of the variable suspending.

The advantage of the stationary and fixed slave arm is the easy handling of big loads and the fast positioning.

For safe fastening and handling of segments during the dismantling of the RPV and its internals a thermal underwater drilling unit has been developed. The unit is working with a contact arc between a cylindrical graphite electrode and the work piece (CAMC = Contact Arc Metal Cutting) and is able to produce defined holes into stainless steel components by moving the electrode continuously through the work piece.

The technical data of the unit are shown in Table 5.

Dimensions of the CAMC device (mm)	400 x 150 x 300
Mass (kg)	30
Electrode	Graphite
Electrode feed (mm)	100
Electrode speed (mm/min)	25 – 60
Current intensity (A)	2 000
Water pressure (hPa)	5 – 8
Water quantity (m^3/h)	3 – 5

Table 5. Technical data of the CAMC

In order to qualify the underwater drilling unit some inactive tests have been carried out at the University of Hannover to determine the parameters and the emissions of the CAMC process.

It was determined that an electrode manufactured from a carbon tube and reinforced with carbon fibre is the best solution regarding the resistance to mechanical damages and abrasion of the electrode.

With a welding source of 2 000 A (DC) at 55 V the graphite electrode (diameter 25 mm) was drilling a hole into a 20 mm thick stainless steel plate within 1 minute.

The consumption of carbon of the electrode was detected to be 2 g for one hole.

The amount of collected gases was about 12 liters. The analysis of these gaseous emissions resulted in a percentage of 25 % CO and 25 % H_2. Hydrogen is generated due to dissociation of water.

4. Steam dryer

The steam dryer was the first RPV-internal which had to be dismantled under water.

The austenitic (X5 CrNi 18 10) component had a mass of 7 Mg and was low activated. The diameter of the component was 3.4 m, the height nearly 4 m.

The outer shell was made out of 5 mm austenitic material with a contamination of about 6 000 Bq/cm^2.

Fig. 9 shows the inner structures of the steam dryer without the outer shell. The 60 vertical standpipes (88 x 2 mm) were welded orbitally to support rings. The 24 dryer bundles were placed in two rings in the upper centre part.

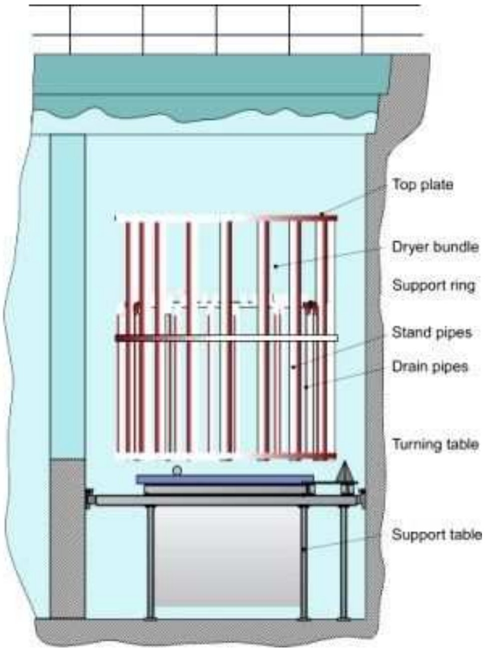

Figure 9. RPV steam dryer without the outer shielding

The given layout of the steam dryer necessitated the establishment of a dismantling concept based on segmenting from the outside to the inside and from the upper part to the lower part.

For the cutting of this component the cutting system ODIN was used with a 600 A underwater plasma arc torch.

Argon and Nitrogen were used as cutting gases. The first working step was to dismantle the 5 mm thick outer stainless steel shell by plasma arc cutting into pieces of approximately 700 x 400 mm.

Table 6 shows the results of the shell segmenting.

Total cutting length (m)	200
Wall thickness (mm)	5
Cutting current (A)	260
Contact dose rate (in air) (mSv/h)	3 … 5
Contamination (^{60}Co) (Bq/cm^2)	5 800
Nuclide vector	99.6 % ^{60}Co
	0.4 % ^{241}Am
Activation (^{60}Co) (Bq/g)	30
Nuclide vector	56.6 % ^{60}Co
	26.6 % ^{63}Ni
	16.8 % ^{55}Fe
Aerosol concentration (under the hood) (Bq/m^3)	10
Water contamination (Bq/g)	5
Sediment contamination (Bq/g)	4 600

Table 6. Technical data of the manipulators

It could be proved that the conditions of visibility during underwater cutting did not get substantially worse. Also the specific activity of water did not increase.

Most of the kerf material dropped into the collecting baskets at the ground. An increase of the aerosol concentration in the atmosphere has been avoided by an additional installation of a suction device above the cutting torch.

The cutting of the dryer shell resulted into 160 single segments. It was verified, that the shell segments could be prepared for controlled recycling. After 8 hours of electro-polishing the activity of the segments could be reduced to the remaining activation of approximately 30 Bq/g (^{60}Co). This is only 1 % of the total initial activity.

About 1 000 man*hours and a dose of 7 mSv were necessary to remove the shell of the steam dryer.

700 man*hours and 5 mSv have been spent for decontamination of the sheets.

Before further dismantling on the steam dryer, an underwater turning table was installed into the equipment storage pool for easier positioning of cutting tools to the component. It has the following design features: load capacity of 15 Mg for carrying all cylindrical RPV internals, low dead weight (3 Mg), overall height (0.5 m) and high stability.

The dryer supporting construction is made of standpipes, angle bars and several small drainage tubes. These steel profiles were mainly segmented by a special underwater hack-saw which is electrically driven and can be fixed directly to the metal structures by a pneumatic clamping grip (Fig. 10).

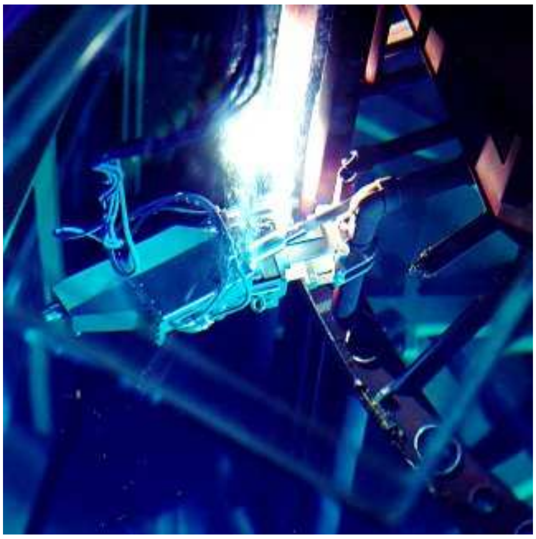

Figure 10. Underwater hacksaw equipped with a pneumatic clamp grip

The hacksaw itself is installed in a housing which is supplied by compressed air. This segmenting tool is found to be reliable and efficient in large-scale application.

E.g. the time for sawing through an austenitic standpipe (diameter 88 mm, thickness 1.5 mm) was about 8 min.

The 50 mm thick support rings were segmented with a special underwater plasma angle torch at a current of 600 A which was attached to the ODIN tool carrier (Fig. 11).

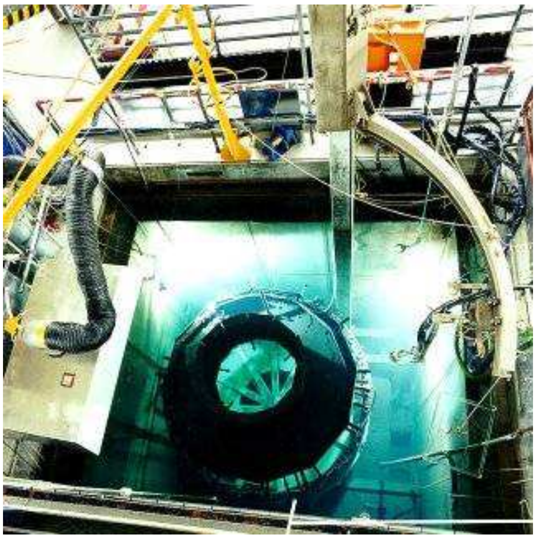

Figure 11. Steam dryer after partial segmenting; on the right the plasma angle torch for segmenting the steam dryer support rings

The support rings were also pre-decontaminated for controlled recycling.

The angle torch was found to be necessary for opening the joint weld at the dryer bundles because the straight plasma torch could not be used due to the narrow space between the two rings of the dryer bundles.

The dryer bundles, the standpipes and the drainage pipes are on stand-by for conditioning as final storage waste.

For the underwater dismantling of the steam dryer a total effort of 7 100 man*hours and a dose uptake of 39 mSv was recorded.

5. Water-steam separator

During plant operation the water-steam separator which is situated below the RPV steam dryer had to be transported together with the steam dryer to the equipment storage pool before refuelling.

The water-steam separator is a combined construction with the core shroud. Fig. 12 shows the schematic layout of water-steam separator.

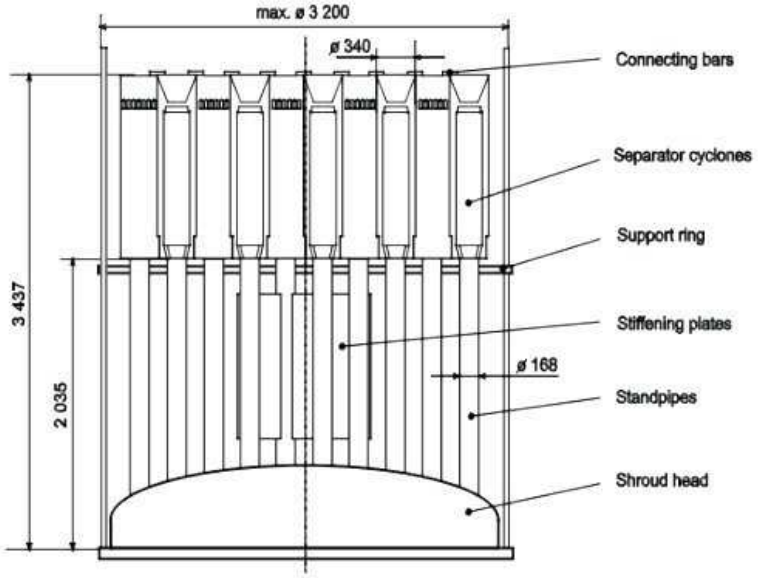

Figure 12. Scheme of the water-steam separator

Each of the 69 water-steam separator cyclones are connected to standpipes above the shroud head.

Looking for an appropriate technique to cut-off the separator pipes from the standpipes under water, studies and inactive pre-tests have been carried out in co-operation with Comex company, Marseille (F).

It was tested, whether the diamond sawing technique with a wrap-around cable at the stainless steel standpipes could be applied for this purpose. The investigations showed that there is, up to now, no reliable diamond cable available on the market which could perform cuts at these pipes without break of the cable (Table 7). Therefore the intention to apply the diamond cable sawing technique has been cancelled.

Sawing with a conventional steel wire		
	Cable diameter (mm)	12.5
	Cutting speed (mm^2/min)	25
Results:		High wire consumption and in consequence a lot of interrupts due to broken wires. Cutting of austenitic material is not economical.
Sawing with a diamond-bead-wire		
	Cable diameter (mm)	9
	Cutting speed (mm^2/min)	130 - 230
Results:		
	a) wrap around method	High wire consumption because of too small bending edges on the end of the cut. Cutting of austenitic material is possible.
	b) guided straight cable	Good cutting results, but a enormous effort of apparatus, equipment and space.

Table 7. Results of the wire sawing tests

The underwater dismantling of the water-steam separator will be executed using the proven segmenting techniques sawing and plasma arc cutting.

To cut the standpipes a new tool carrier was developed. The finally segmenting concept is divided in four steps which are given in Table 8.

Step	Working step	Tool
1	Opening the connecting bars	ODIN with plasma arc
2	Cutting off the separator cyclones	Underwater hack saw
3	Segmenting the standpipes	RAMSES with plasma arc
4	Segmenting the shroud head	ODIN with plasma arc

Table 8. Concept for segmenting the water-steam separator

For dismantling the component was positioned in the storage pool on the turning table.

The first step was to open the connecting bars between the separator cyclones using the handling system ODIN and the plasma torch.

The performance of cuts through a single standpipe (diameter 168 mm, wall thickness 7 mm) is being complicated due to its compact arrangement with only 200 mm space to each other. The dismantling of the standpipes was done in two steps: cutting off the cyclones and segmenting the standpipes.

Two different tools were used: the already proven underwater hacksaw with a modified pneumatic clamping grip (Fig. 13) and a new automatically driven plasma arc device called RAMSES (Fig. 14).

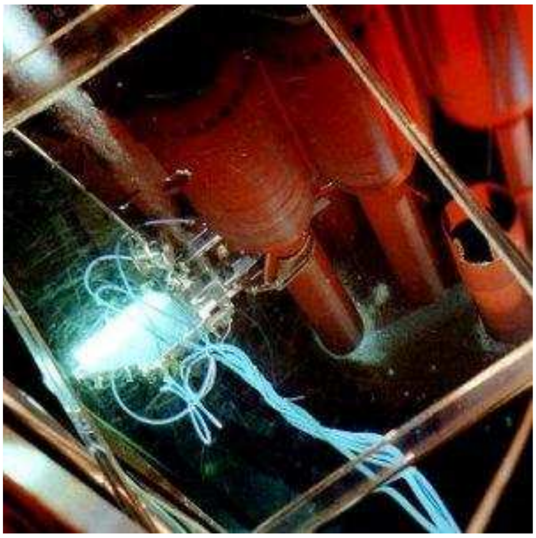

Figure 13. Underwater hack saw cutting off a separator cyclone

Figure 14. The plasma cutting device during segmenting the stand pipes (the cutting time for each pipe using a 100 A plasma torch was approximately 1 minute)

The automatically driven thermal cutting device with an orbital moving plasma torch was developed together with the University of Hannover.

The cutting unit is equipped with a self fixing pneumatic gripping device. The plasma arc torch runs along a belt driven guiding rail 180° to each side.

Thus the execution of a complete 360° orbital cut is possible.

After segmenting the standpipes the shroud head will be segmented by plasma arc cutting.

Fig. 15 shows the actual situation of the water-steam separator.

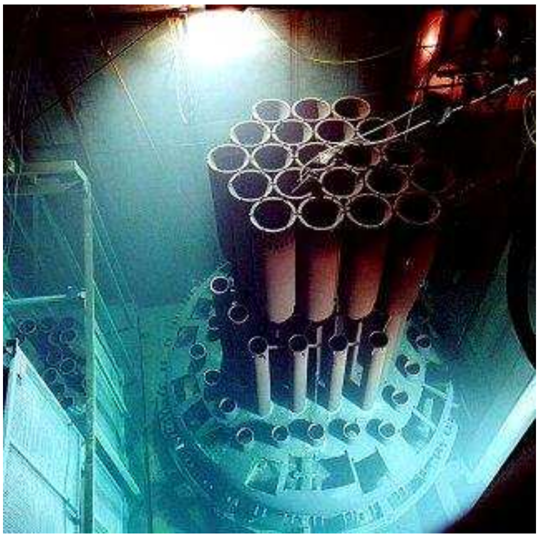

Figure 15. Actual situation at the water-steam separator dismantling

6. Feedwater sparger

The feedwater sparger in KRB-A consists of 2 sparger halves which are mirror-inverted, and mounted just above the upper grid plate in the RPV (Fig. 16). The major technical data are shown in Table 9.

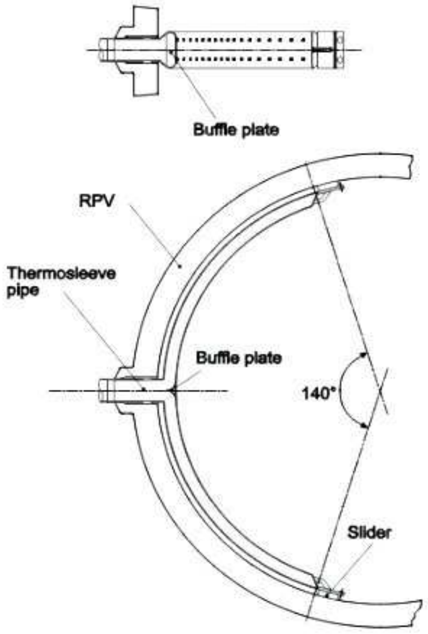

Figure 16. One half of the feedwater sparger

	Thermosleeve	Sparger	Adapter
Material	X10 CrNiNb 18 9	X5 CrNiTi 18 9	Inconell 600
Wall thickness (mm)	8 (13)	8	27
Mass (kg)	160 per Sparger		

Table 9. Technical data of the feedwater sparger

During an outage in 1976, it was discovered that the feedwater sparger was deformed and showed cracks.

This feedwater sparger was exchanged by a divers applying underwater plasma arc cutting and welding out of a shielded underwater cabin. The effort for exchanging of the component was 6 000 h, the collective dose was 1.3 Sv. The new feedwater sparger had only been in operation for 4 months until the reactor was finally shut down.

A calculation of the NIS company pointed out that the overall activity of the renewed sparger is only 3 10^5 Bq.

Because of the low activation the post-segmenting will be done at the atmosphere with a band saw.

Fig. 17 gives a partial view to the feedwater sparger inside the reactor.

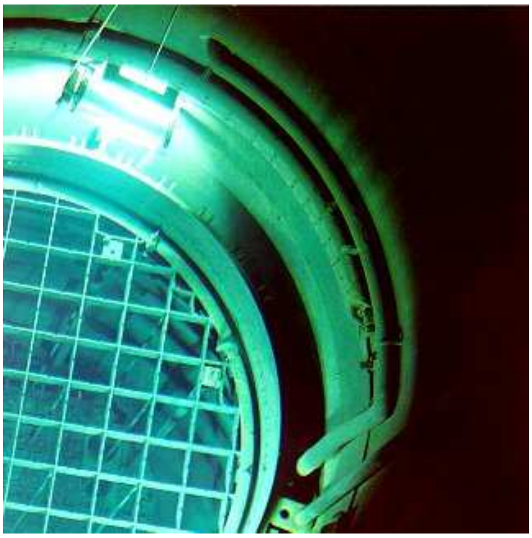

Figure 17. Feedwater sparger with a slider

Disassembling of the sparger can be accomplished by just cutting through the thermosleeve pipes between the sparger and the reactor wall.

The only problem is the narrow space of 14 mm for segmenting. For economic efficiency it was decided to use an underwater hack-saw with a modified clamping and blade guide device.

It is foreseen to start with the dismantling in the first quarter of 1997. The actual planning calculates with a collective dose of 6.2 mSv and an effort of 650 h.

7. Control rods

The 89 control rods of KRB-A are highly activated components.

The ^{60}Co activity of one control rod was about 1.85 10^{13} Bq.

The cross-shaped construction of the control rods is equipped with small tubes filled with B_4C powder. At the top end of each control rod, 4 mainly cobalt-consisting stellite balls are installed for guiding the control rods inside the reactor core. However, the four stellite balls with a mass of only 50 g each, are containing 65 % of the total ^{60}Co inventory of each rod.

It has been decided to start the dismantling of the control rods by removal and collecting of all stellite balls first.

By following this concept, the highly activated balls with dose rates up to 150 Sv/h can be inserted into a separate thick-walled waste container, whereas waste containers with a smaller shielding can be used for disposal of the major amount resulting from the subsequent segmenting of the main structure of the control rods. A hydraulic press has been developed and manufactured for mechanical removal of the 400 stellite balls.

The removal of all stellite balls had an effort of 206 man*hours and a dose of 2.4 mSv.

Also, a hydraulic underwater shear has been bought for common use with VAK, Kahl, in order to segment the control rods and other RPV internals of both plants.

The underwater shear is equipped with a pre-compaction and a shearing unit. Fig. 18 shows the principle of the underwater shear.

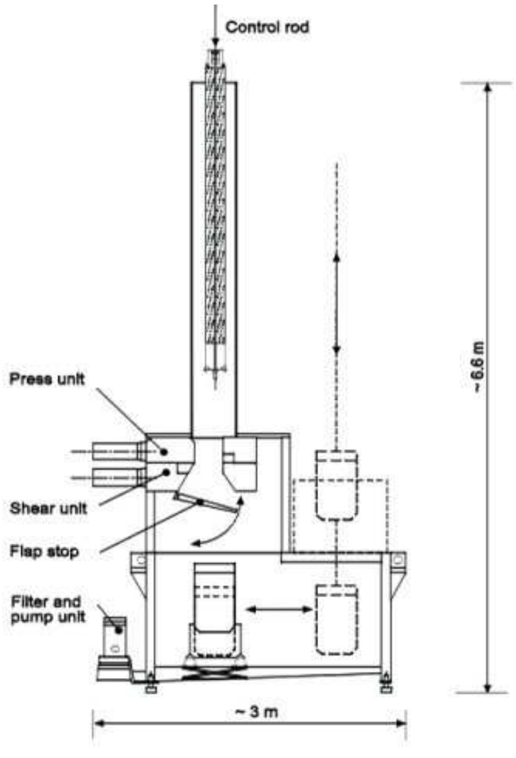

Figure 18. Principle of the underwater shear for the segmenting of the control rods

For the first time in Europe, the conditioning of highly activated control rods by underwater segmenting was realized at VAK. Especially the release of Tritium during shearing has been investigated by this pilot conditioning of the VAK control rods, which had been in operation for 25 years.

The shear as well as the positive results obtained in VAK were also used in KRB-A.

Fig. 19 and 20 show the underwater shear during shearing in the fuel element storage pool of KRB-A.

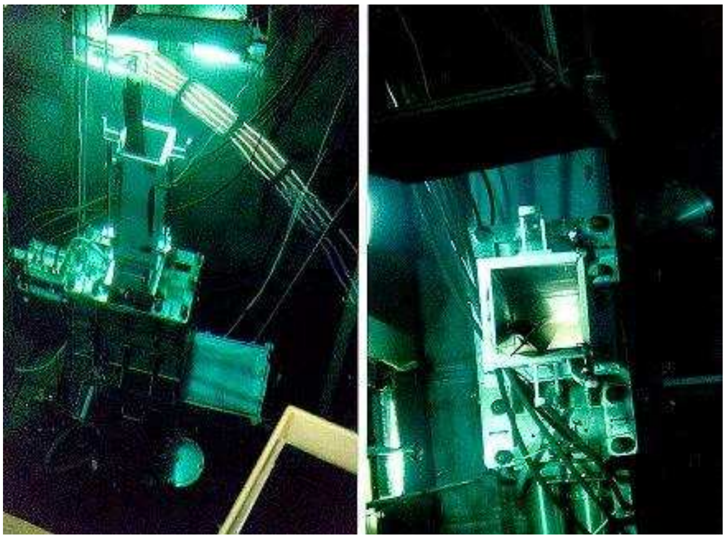

Figure 19 and 20. Underwater shear during shearing

The shearing campaign of the first 30 control rods ended in January 1997. The results are shown in Table 10.

Length of the rods (mm)	3 715
Mass per control rod	
Austenitic steel material (kg)	51.3
B_4C powder (kg)	5,5
Stellite ball (kg)	0.011
Activity (Bq)	4 . 10^{12} (without stellite balls)
Tritium inventory (Bq/rod)	1.9 . 10^{10}
Released gas (l/rod)	0 ... 3
Cutting rate (rods/day)	2
Packing (rods/container)	3
Tritium activity in air	no increase
Tritium activity in water	no increase

Table 10. Results of shearing 30 control rods

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8. Top guide

The total activity of the top guide is calculated by NIS company to be $7.8 \cdot 10^8$ Bq/g.

This means that the top guide is the highest activated component of the RPV regarding the mass specific activity. Therefore remote controlled segmenting, handling and packing is absolutely necessary.

The mass of the austenitic component is 1.3 Mg, the wall thickness is 8 to 35 mm, the plates of the upper grid are 11 mm thick. The grid has an outer diameter of 3 035 mm and a height of 194 mm.

Fig. 21 shows the top guide at its installation place in the reactor core.

Because of the high activation a mechanic segmenting technique will be favourable for segmenting the single grid plates.

It was decided to use a hacksaw having the following features:

- underwater use for a water depth of 15 m,
- self clamping,
- simple design, and
- remote-controlled.

Together with the company HWM, Markdorf, a commercial hacksaw with a 60 mm stroke was cased into an austenitic housing. The housing is supplied by compressed air to avoid water diffusing into the inside of the housing.

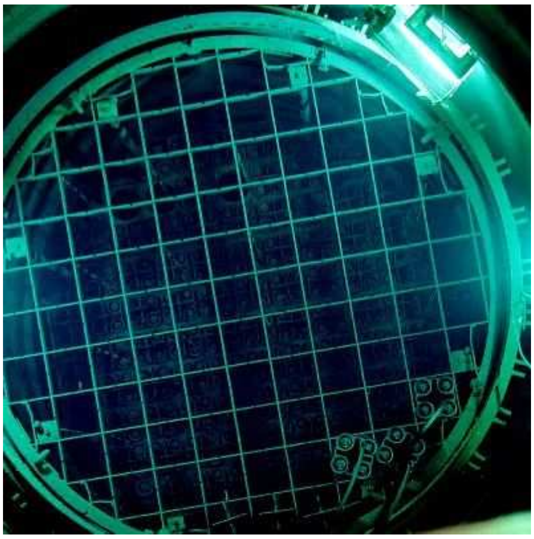

Figure 21. View to the top guide inside the reactor

Fig. 22 shows the general layout of the saw mounted on the top guide.

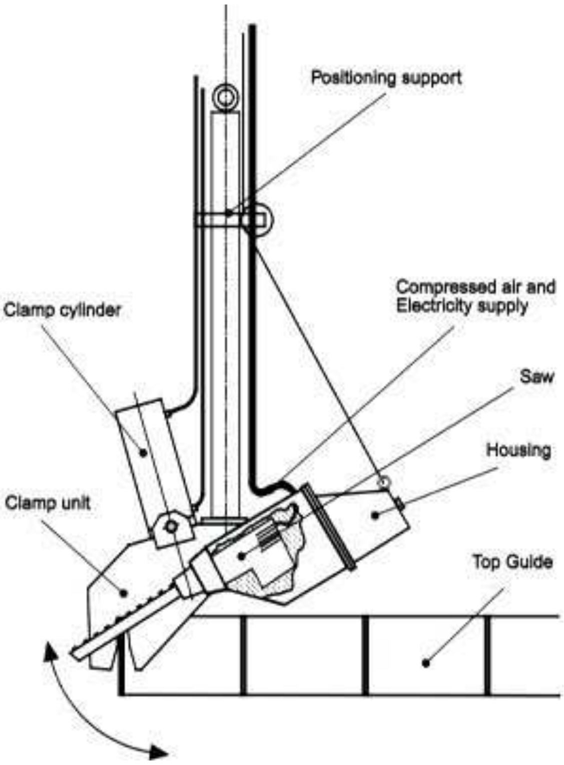

Figure 22. General layout of the underwater hacksaw clamped on the top guide

The inactive tests at a top guide model showed that the segmenting time for one grid (11 mm x 190 mm) was about 50 minutes. No problems occurred during the tests.

It is planned to start segmenting of the top guide in the middle of 1997.

9. Core support

The core support of KRB-A had to carry all the load of the fuel elements, totally 53 Mg of UO_2, during operation. Therefore the plate is considered to be a very solid and strong construction.

The outer diameter amounts to 2 921 mm and the height to 384 mm. The activation is $1.7 \cdot 10^8$ Bq/g ^{60}Co, the mass 1 400 kg and the wall thickness ranges between 8 and 38 mm.

The schematic design of the core support is shown on Fig. 23.

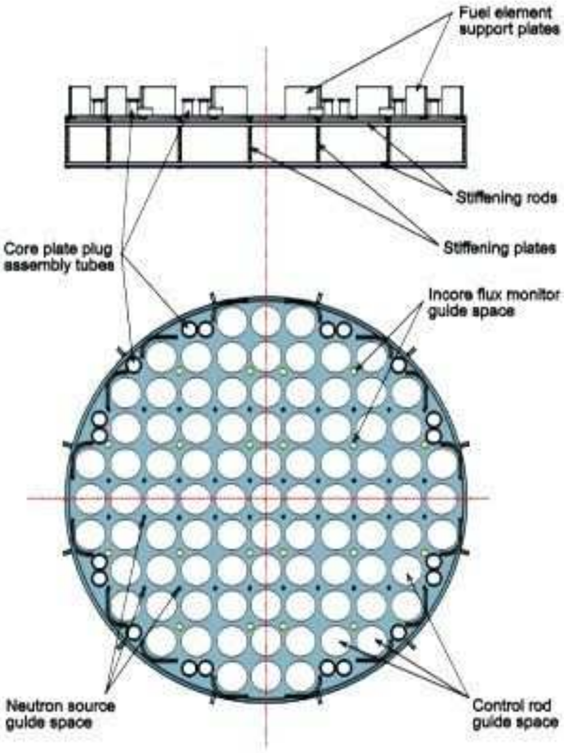

Figure 23. Design of the core support

Just like dismantling the rest of the RPV internals the core support has to be segmented under water for final storage.

Some dismantling work like opening weldings, to allow unscrewing, have to be done already inside the RPV vessel.

After the component has been removed from the RPV, segmenting will be executed in the equipment storage pool.

It is intended to use the plasma arc torch and the hacksaw for the segmenting. The special angle plasma arc torch will be suitable to penetrate the 228 mm openings of the core support. The stiffening rods below the plate are complicating the segmenting procedure. It is intended to segment the component by means of a hacksaw or by applying the plasma arc cutting technique.

Segmenting of the core support may start after removing the top grid and before dismantling the core shroud. It is planned to finish the segmenting during the second half of 1997.

10. Core shroud

The core shroud with a mass specific activity of $8.2\cdot10^7$ Bq/g is one of the highest activated components in the RPV.

Due to its height of 7.7 m it is not possible to disassemble the component in one piece. The core shroud had to be segmented under water by applying remote-controlled cutting and handling techniques.

The design and dimensions of the component are shown on Fig. 24.

For the dismantling planning the core shroud was divided into the following sections:

- upper part with core spray sparger,
- cylindrical shroud around the core,
- core shroud support,
- core shroud lower part, and
- support ring of the core shroud.

The technical data of the core shroud are given in Table 11.

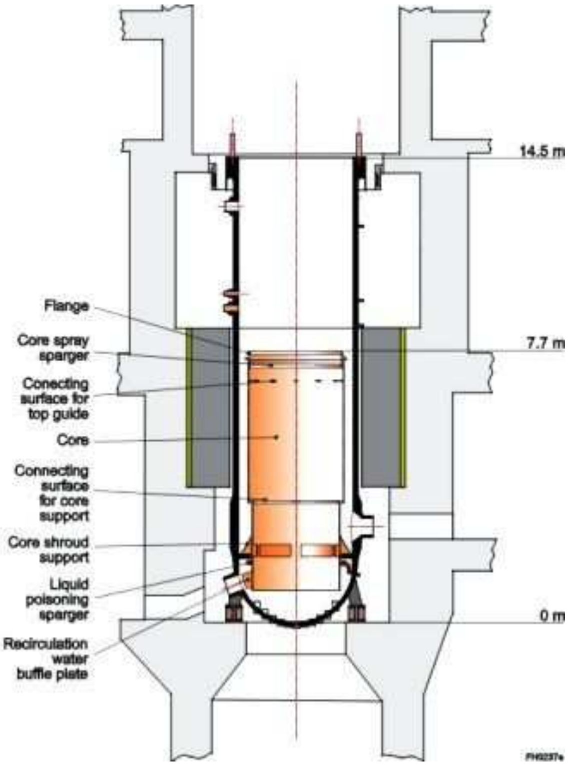

Figure 24. Design of the core shroud

Mass (Mg)	16
Material	X5 CrNi 18 9
Outer diameter (mm)	2 900 ... 3 200
Height (mm)	7 740
Wall thickness (mm)	25 ... 38
Specific activity (Bq/g)	$8.2 \cdot 10^7$

Table 11. Technical data of the core shroud

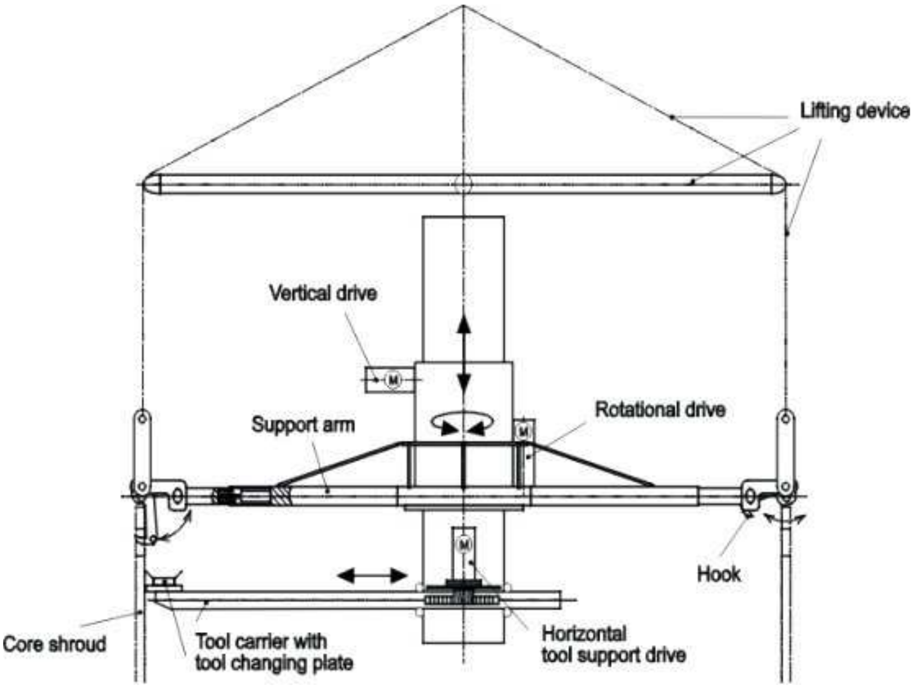

Figure 25. Ring type segmenting unit for dismantling the core shroud

Generally, the following working steps are carried out:

- development and qualification of a tool carrier,

- development of a handling unit for the segments,
- segmenting of the core shroud inside the reactor, and
- post-segmenting and packaging of the segments into waste containers.

Six different companies were asked for the finally design and construction of the tool carrier.

The bids were investigated for the technical solution, simple design and economy. The company Steinmüller, Gummersbach, got the bid with the solution shown on Fig. 25.

The result was a ring type segmenting unit equipped with an orbital moving tool carrier to cut of single rings with a underwater plasma arc.

The tool carrier will cut the core shroud in segments between 150 mm and 850 mm height and carry them to the storage pool.

The post segmentation will be done with ODIN and the underwater plasma torch. The cutting unit is now under detailed planning and will be available for active implementation by mid-1997.

11. Studies of the RPV segmenting

After removal and dismantling of all RPV internals, the RPV vessel itself will be segmented.

For that purpose thermal or mechanical cutting techniques under water or in atmosphere are possible.

Fig. 26 shows the initial situation prior the RPV dismantling.

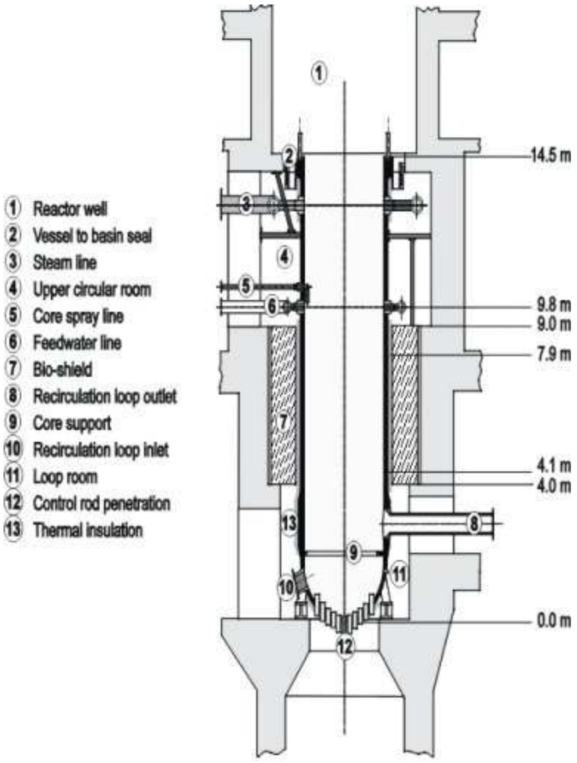

Figure 26. Initial situation prior RPV dismantling

The RPV activity and the resulting aerosol generation during segmenting are the most important criteria for the selection of appropriated segmenting techniques.

Table 12 shows the activity profile for the RPV. Before dismantling, the RPV will be cleaned to remove the dirt particles and the loosely adhering contamination layer.

This will be done with the modified core shroud segmenting unit.

Fig. 27 illustrates the situation above the bio-shield in the upper circular room (+17.9 m).

This picture also shows the blanking plugs of core drillings at the RPV which have already been performed in the year 1984.

RPV-area		**Mass (Mg)**	**Activity in the year (Bq)**		
			1987	**1997**	**2007**
Cover	**base material**	60	1.3×10^{5}	1.4×10^{4}	3.5×10^{3}
Cover	**cladding**	3.4	1.0×10^{6}	3.7×10^{5}	2.9×10^{5}
Flange	**base material**	56	2.3×10^{4}	2.4×10^{3}	0
Flange	**cladding**	2.1	1.9×10^{3}	6.2×10^{2}	3.9×10^{2}
Dryer area	**base material**	21	9.6×10^{4}	1.1×10^{4}	3.1×10^{3}
Dryer area	**cladding**	1.6	1.3×10^{4}	4.5×10^{3}	3.3×10^{3}
Feedwater inlet	**base material**	20	3.6×10^{8}	4.3×10^{7}	1.2×10^{7}
Feedwater inlet	**cladding**	1.6	5.1×10^{7}	1.8×10^{7}	1.3×10^{7}
Upper core area	**base material**	18	2.3×10^{10}	3.2×10^{9}	8.9×10^{8}
Upper core area	**cladding**	1.4	3.4×10^{9}	1.2×10^{9}	8.1×10^{8}
Centre core area	**base material**	32	2.6×10^{13}	3.1×10^{12}	8.7×10^{11}
Centre core area	**cladding**	2.5	3.7×10^{12}	1.3×10^{12}	1.0×10^{12}
Lower core area	**base material**	21	2.7×10^{10}	3.7×10^{9}	1.0×10^{9}
Lower core area	**cladding**	1	2.4×10^{9}	8.4×10^{8}	5.9×10^{8}
Loop room area	**base material**	38	5.2×10^{10}	5.8×10^{9}	1.8×10^{9}
Loop room area	**cladding**	1.8	3.1×10^{9}	1.1×10^{9}	8.8×10^{8}
Bottom dome	**base material**	20	-	-	-
Bottom dome	**cladding**	20	-	-	-

Table 12. Activity profile for the RPV

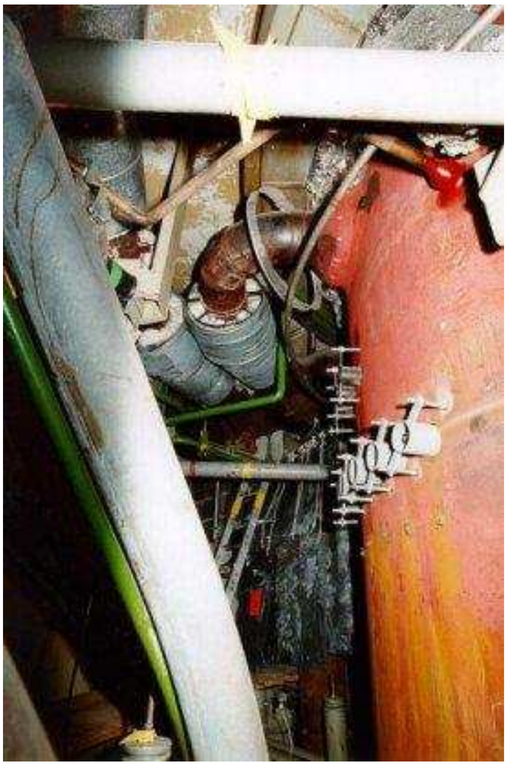

Figure 27. Situation in the upper circular room, above the bio-shield

Most of the thermal insulation (about 60 mm aluminium foil) at the outer RPV wall is removed but a lot of bolts and pipes are still in place.

The local dose rates at the RPV are shown in Table 12.

Location	**Contact dose rate (µSv/h)**	**1 m distance dose rate (µSv/h)**
Reactor floor, + 31.8 m	-	10
Upper circular room, + 17.9 m	910	170
Loop room, + 8,9 m	370	70

Table 12. Local dose rate at the RPV

Six nuclear service companies have been asked to provide a proposal for dismantling of the RPV. After evaluation of the proposals, the companies DETEC-MAN GHH and NOELL have been commissioned to work out a dismantling and handling concept.

The DETEC-MAN GHH concept is characterized by applying thermal cutting techniques for the upper and lower part of the RPV (Fig. 28) whereas the core section is segmented by sawing using a ring-type tool carrier (Fig. 29).

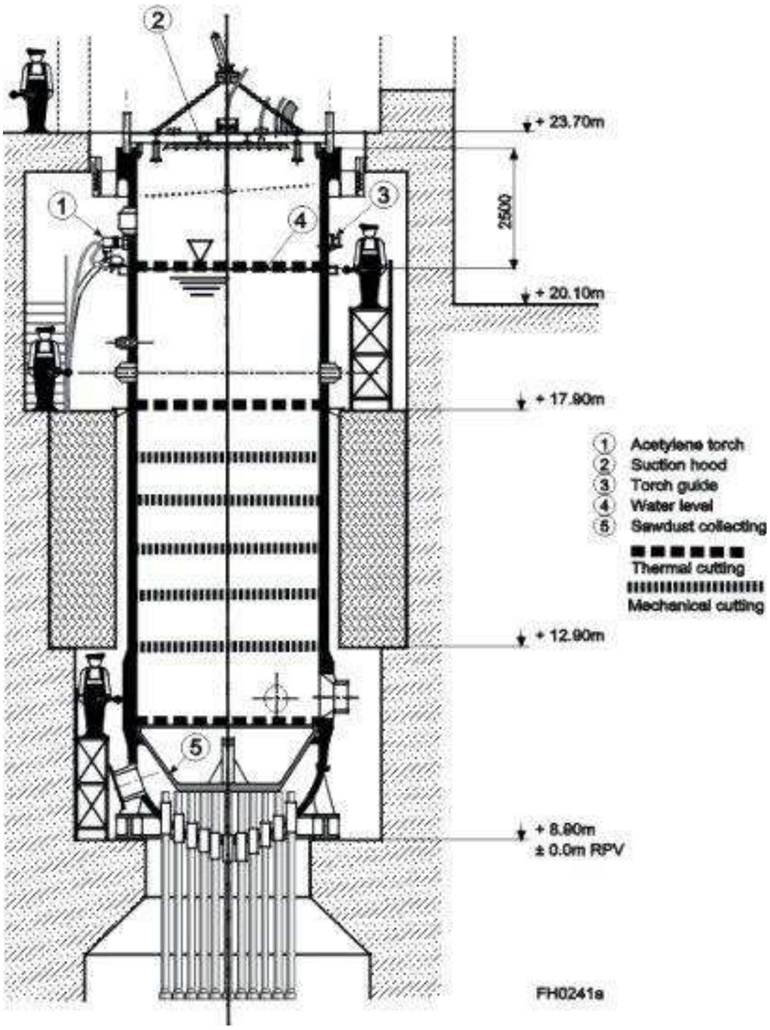

Figure 28. RPV-segmenting and handling concept (Detec-MAN consortium)

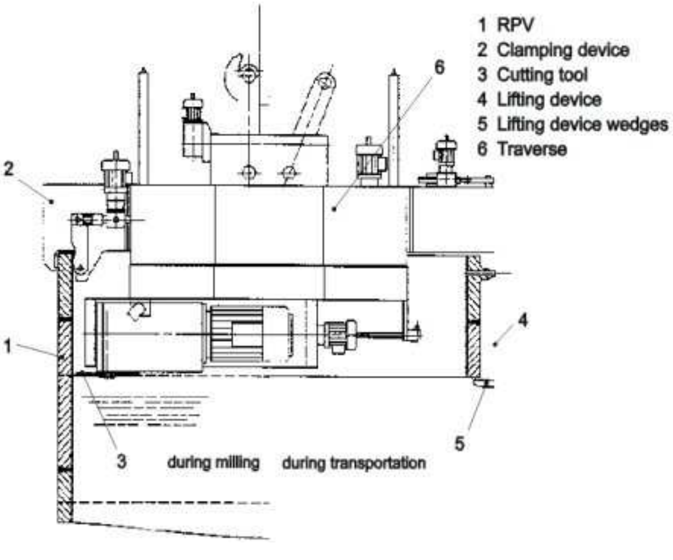

Figure 29. Milling unit for segmenting the core area

The thermal cutting will be executed by a acetylene torch which is fixed on a chain driven tractor and run around the RPV on a rail. To reduce the aerosol emission the RPV is always filled with the maximum possible water level during cutting.

The torch has an inclination of about 30° so the cutting flame entry is above the water level and the exit is under water. By this procedure the cutting depth is increased from 124 mm to 151 mm.

During the thermal cutting a suction cover will be installed at the open ending of the RPV so all emitted aerosols can be collected. During the cutting progress, wedges will be manually pushed into the gap between the RPV and the cut off segment in order to keep the segment in position. A traverse transports the cut off segments to the thermal post segmenting in a temporary tent on the reactor floor.

A milling unit is foreseen to segment the core area of the RPV (Fig. 29). After the unit is set on the RPV and fixed by clamping devices at the wall, the milling tool can be started. During milling, lifting device wedges had to be turned into the cut to fix the cut off segment for the transportation. The cutting is visually and acoustically controlled to avoid tool damage.

The post segmenting is done on a turning table inside the fuel element storage pool. An acetylene torch is adapted at a remote-controlled handling and cutting system. A suction hood above the turning table collects the emitted aerosols.

The RPV underneath the bio-shielding will be dismantled similar to the parts above the bio-shielding. The post segmenting procedure will also be the same.

The effort for dismantling the RPV is calculated with 12 600 man*hours so a team of 7 people will take about 50 weeks.

The collective dose is calculated with 246 mSv.

The DETEC-MAN GHH concept investigated the packaging by conventional cast-steel containers and the new onion casting technique. All together 249 Mg of RPV-material have to be handled. 6 Mg of swarf material will be produced.

Table 14 shows the RPV segments and the activity.

	Dimensions Ø x H (mm)	**Mass (Mg)**	**Specific activity (Bq/g)**	**Post segmenting Segment**	**Cutting lengths**	
					Thermal (m)	**Mechanical (m)**
Segment 1 with cover bolts	5 785 x 2 500	58	< 1	12	40	-
Segment 2	4 430 x 2 600	32.5	< 2.2	12	41	-
Segment 3	3 970 x 5 400	67	< 10^5	45(1)	48(1)	63(1)
				88(2)	93(2)	63(2)
Segment 4	4 152 x 2 400	48	< 190	27	61	-
Calotte	4 560 x 1 900	26	< 1	36	50	-
Support	4 470 x 600	8	< 1	-	-	-
Control rod penetration	222 x 3 024	9.5	< 1	-	-	-

(1) Onion cast container.
(2) Standard Konrad container.

Table 14. Activity and mass of the RPV segments

The specific activity of segment 3 is more than 200 Bq/g and has to be treated as waste. The rest of the RPV can be controlled recycled by melting after decontamination.

The conventional packaging variant uses for the low activation normal containers with a concrete fixing and for high activation the steel-cast containers. The volume for final storage by this variant is 64.5 m^3. The onion casting variant needs 15 cast containers with half the size of a conventional Konrad container. The parts of segment 3 will be packed into the containers and fixed with the molten segment 4. The volume for final storage by this variant is 40.8 m^3.

The NOELL concept follows the idea of pre-segmentation of the RPV wall by 7 horizontally sawing under water, and completing the cutting after reducing the water level for cutting through in atmosphere. The RPV will be segmented with a dismantling unit into seven parts. The seven segments will be transported to the fuel element storage pool for underwater post segmenting with a band saw.

The dismantling unit is divided into two parts: the lower ring type tool carrier and the upper fixing and handling traverse. The tool carrier is equipped with a turning plate, a drilling unit and a milling unit. The traverse is equipped with a fixing device to handle the segment safely.

Figure 30 shows the dismantling unit.

For decommissioning, the unit will be lowered into the water filled RPV.

The holding device (7) will fix it so the drilling unit (5) can drill three stop holes (8) for locking the traverse (1).

When the traverse is locked the milling unit (6) will cut about 80% of the RPV wall under water. Afterwards the water level will be lowered and the circular saw (4) will cut the residual 20% of the RPV wall in atmosphere.

The cut off segment will be transported with the traverse to an underwater turning table in the fuel element storage pool for post segmenting with a band saw.

Fig. 31 shows the concept during lifting the first came off segment. During transportation the tool carrier will stay in the RPV. The post segmenting in the fuel element storage pool will be done with a underwater band saw. For handling the post segmented RPV parts fastening holes will be produced with a thermal drilling unit.

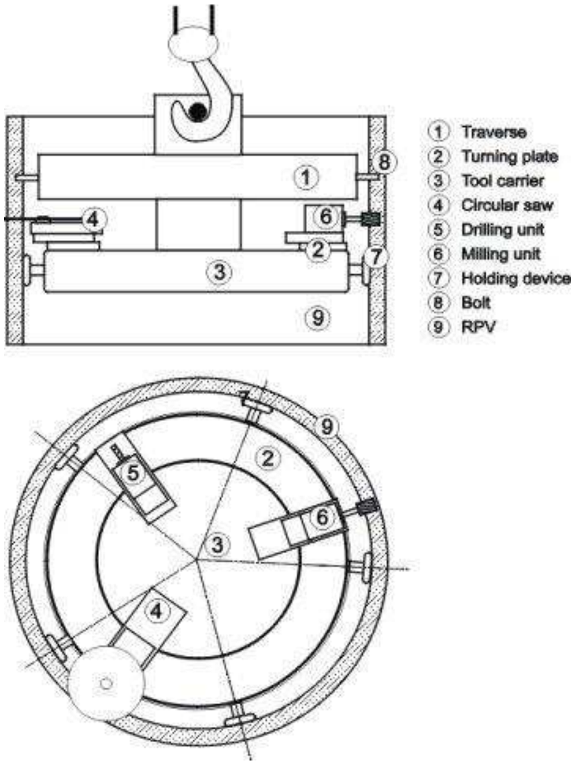

Figure 30. Dismantling unit for RPV decommissioning

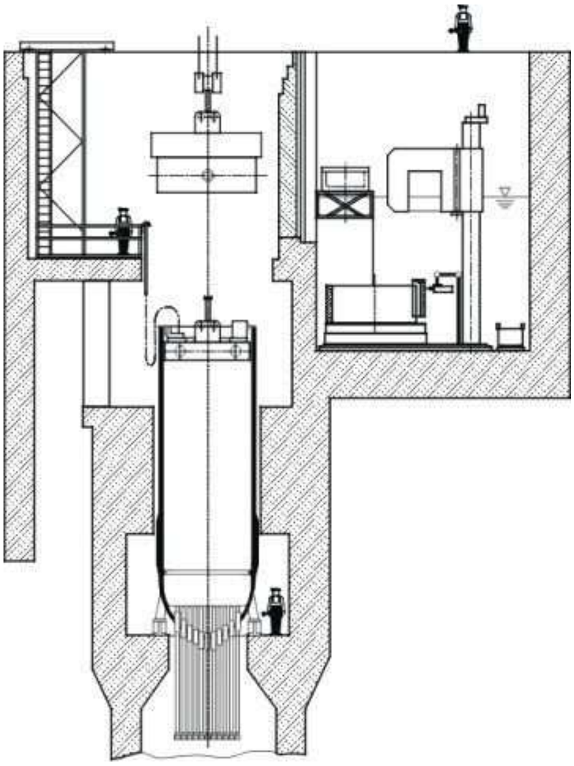

Figure 31. RPV-segmenting and handling concept (Noell company)

For selecting the final RPV segmenting technique and packaging variant further investigations on the RPV activation are needed for the detailed planning.

This will be carried out by a further EU contract: RPV and internals dismantling project, research contract n°. FI4D-CT95-0001.

12. Planning and testing of the bio-shield segmenting

In order to test different concrete cutting techniques in regard of the future segmenting of the activated biological shield, an inactive mock-up of the biological shield has been built-up on the KRB-site (Fig. 32.

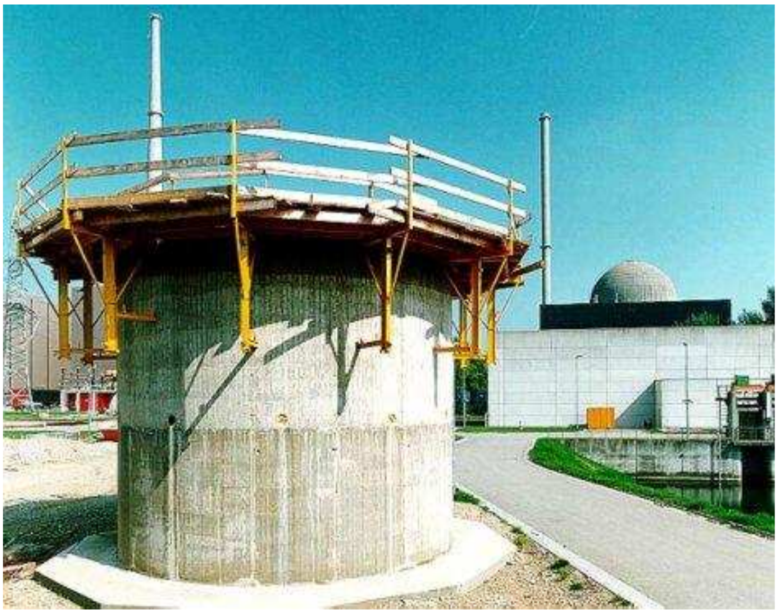

Figure 32.Mock-up of the biological shield

The main data of the 116 m^3 concrete biological shield are given in Table 15.

	Mass (Mg)	Activity (Bq)
Concrete	265	2.5×10^{11}
Reinforcement	7.5	1.5×10^{11}
Steel liner	2.5	1.5×10^{11}
Shield cooling	5	1×10^{11}
Total	280	6.5×10^{11}

Table 15. Main data of the biological shield

In parallel, a literature study on principally suited concrete-segmenting techniques was carried out at the University of Hannover. Different mechanical and thermal techniques were investigated and evaluated for an active implementation with special regard of the conditions in KRB-A.

As a result, the diamond cable sawing and the chain sawing were found to be the most suitable concrete cutting techniques.

The diamond cable cutting technique was first tested at a thick-walled reinforced shielding wall in the turbine house. The following process parameters have been obtained: the cutting of the 1 m thick wall was done by using different diamond cables with a total length of 36 m. A cutting surface of 50 m^2 was produced giving a number of 20 single concrete blocks, 2 Mg each.

The total effort of 470 man*hours for this task includes all necessary work like fixing the diamond cable saw at the wall, installation of cameras for the control of the cutting process and recycling of the cooling water. After the successful segmenting of the shielding a test series was started at the inactive mock-up.

In the model all important details, e.g. dimensions, reinforcement, vertical cooling tubes and a steel liner at the inside of the structure have been materialized. The wall thickness is 1.3 m, whereas the height is 4 m (original: 5 m).

The first step when dismantling the biological shield will be the removal of the inner steel liner of 3 mm thickness into 0.6 m sheets to lower the local dose rate. The cutting was performed remotely-controlled by a hydraulic driven circular saw running on a suction system fixed vertical guide rail. The diamond blade of the saw was cooled by water. Only the short horizontal cuts had to be performed manually using a conventional grinding machine.

Two optional cutting techniques have been investigated for its time consumption for assembling and cutting, the consumption of wear material and the production of secondary waste.

The application of diamond cable cutting provides a horizontal and vertical core boring to insert the diamond cable to a whole loop for operation. Three cuts were done with the diamond cable cutting from the top side of the model without substantial problems; Fig. 33 shows the diamond cable.

One cut was performed with a chain saw which was vertically guided by a special rail at the inside of the model. This cut was performed in two steps by first using a blade of 0.6 m and subsequently one of 1.6 m length.

During chain cutting some problems occurred due to damage to one chain segment.

Figure 33. Diamond cable cutting equipment at the bio-shield mock-up

Altogether three concrete blocks, 20 Mg each, have been cut-off and lifted-up from the remaining model of the biological shield. The main results of the tests are given in Table 16.

The table shows that the diamond cable sawing technique has an easier collecting system for spray water, a smaller sludge generation and a higher reliability. Therefore this technique should be preferred for the implementation at the real biological shield.

1. Removal of the steel liner (per sheet 4 m x 0.6 m)			
- Assembling and disassembling of the tool	(h)	0.8	
- Time for cutting	(h)	1.8	
2. Core drilling (d = 125 mm)		Vertical	Horizontal
- Depth of boring	(m)	4.0	0.5
- Assembling and disassembling of the tool	(h)	2.3	1.2
- Time for drilling	(h)	3.0	0.4
3. Concrete segmenting (per cut 5.1 m^2)		Diamond cable saw	Diamond chain saw
- Assembling and disassembling of the tool	(h)	5.8	5.2
- Time for segmenting	(h)	5.1	6.8
- Kerf width	(mm)	11.0	16.0
- Water consumption	(m^3)	4.0	4.0
- Wire/chain consumption	(m)	10.0	1.0
- Sludge arising	(m^3)	0.1	0.2

Table 16. Results of inactive tests at the mock-up of the biological shield