

DISMANTLING AND DECOMMISSIONING TECHNOLOGIES AND TECHNIQUES FOR RESEARCH REACTORS

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INTRODUCTION

More than 150 research reactors have been shut down worldwide and are to be dismantled, among them, for the time being, four reactors in Germany and 106 reactors in the USA (according to IAEA information). The Research and Measurement Reactor (FMRB) of the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, a swimming pool reactor of the MTR type (Material Test Reactor), light-water moderated, with a heavy-water system for coupling a split core and a thermal column made of graphite, combines the most diverse characteristics of different types of research reactors, and its dismantling may generally serve as an example of research reactor dismantling.

The FMRB was finally shut down in December 1995, after 28 years of operation. The activated and contaminated parts of the FMRB are to be disposed of as quickly as possible to allow the remaining buildings to be used soon for conventional purposes/1/. It is planned to emplace the resulting radioactive waste into an interim storage or in a final repository. Only the activated and contaminated parts are to be removed, conditioned and disposed of under the laws and regulations applicable to the construction, operation and decommissioning of a reactor. The remaining buildings and the remaining equipment will be dismantled and removed in a conventional way. This way of proceeding will shorten the whole decommissioning procedure and save time and money.

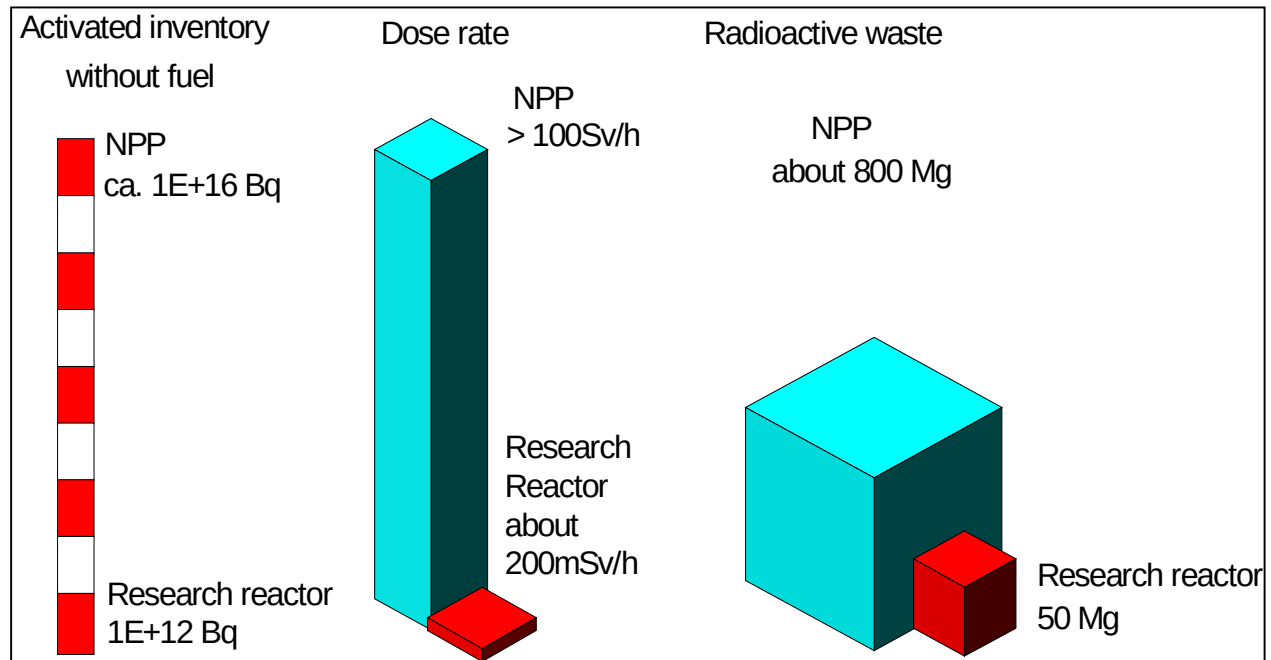
GENERAL SITUATION

To make the situation quite clear from which dismantling of a research reactor is started, the FMRB is in the following compared with a power reactor as regards its radioactivity inventory, the dose rates, the mass of waste arisings and the risk potential resulting from it (Fig. 1).

Like a power reactor, the FMRB is a stationary plant for the fission of nuclear fuels, whose operation was licensed under the relevant laws and regulations. Accordingly, decommissioning and dismantling are formally to be handled under licensing law in the same way as would be the case with power reactors. Despite this, there are de facto substantial differences between research reactors and power reactors, which have an effect also on the licensing requirements.

The radioactivity inventory of the FMRB is about $1 \cdot 10^{12}$ Bq and, after 28 years of operation, by about four orders of magnitude lower than that of a power reactor whose radioactivity inventory is about $1 \cdot 10^{16}$ Bq /2/, in both cases after unloading of the fuel elements. This is due to the low thermal power of research reactors, resulting in a lower activation of the internals near the core, which are almost exclusively made of aluminium in research reactors.

Fig. 1: Comparison: Nuclear Power Plant (NPP) and reactor and research reactor

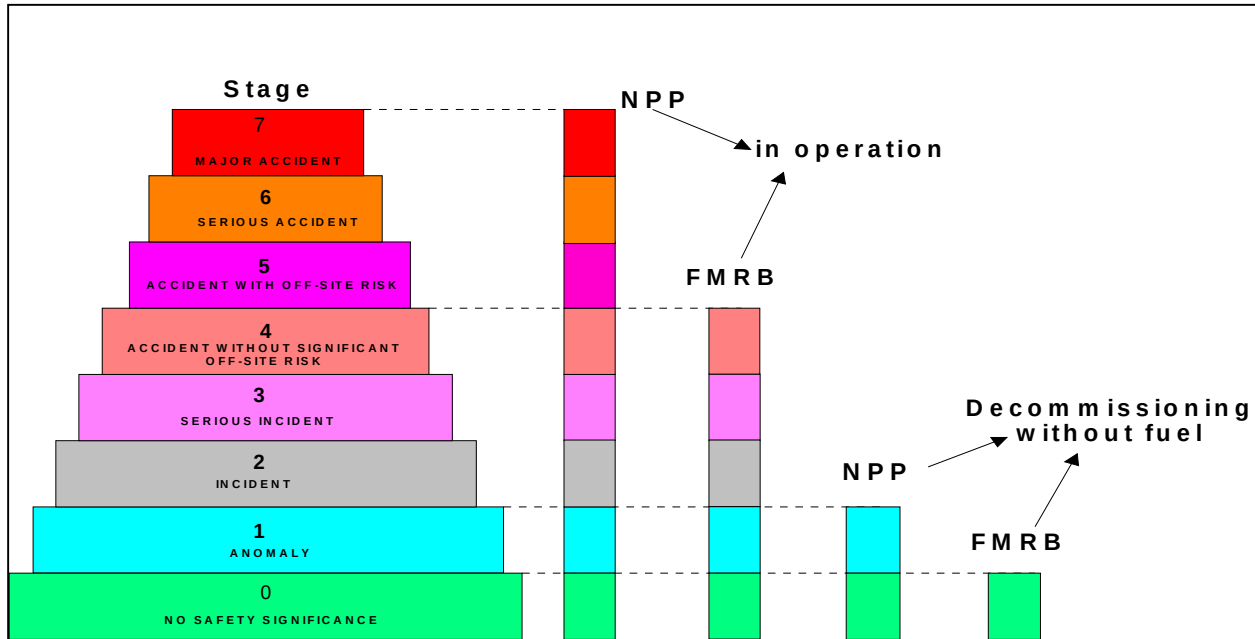


The maximum local dose rate in the pool of the FMRB, without water covering and fuel, is about 200 mSv/h. It is thus very low compared with a few hundred Sv/h in power reactors.

Only about 50 Mg of activated and contaminated waste will arise during dismantling of the FMRB (reactor tank with internals and biological shield). The comparable figure for a power reactor (only reactor pressure vessel with internals) is about 800 Mg.

Already during operation of the FMRB the danger potential was considerably lower than that of a nuclear power plant. Owing to the design, accidents above the INES 4 level/3/ could not occur in the FMRB. Disturbances can still occur during dismantling of the FMRB, which are to be assigned at most to stage 1 of the INES scale (Fig. 2). However, possible impacts on the environment are by a few orders of magnitude lower than the impacts often encountered during power reactor dismantling, although these, too, are low. Safety considerations for the dismantling of the FMRB have shown that, when a conservative approach is chosen, in the case of an incident covering all other possible incidents the maximum radiation exposure of third parties is by about six orders of magnitude below the limiting value valid in Germany. Compared with natural radiation exposure this value thus is approximately zero.

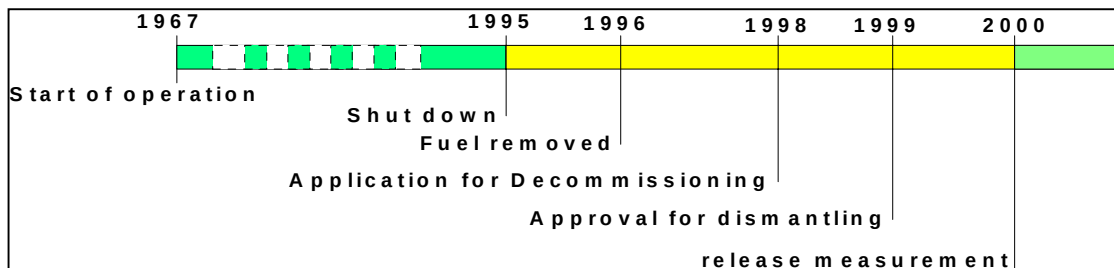
Fig. 2: The International Nuclear Event Scale (INES)



This favourable situation at the FMRB has been taken into consideration when the approval documents were drawn up, including the description of the dismantling techniques.

As already mentioned, the FMRB was shut down in 1995. In 1996, the fuel elements were transported under the non proliferation policy to the USA, and the application for decommissioning and partial dismantling was filed in January 1998. We hope to obtain the respective approval and be able to start dismantling in 1999. As Germany does not have at present a repository for this radioactive waste, the waste will be conditioned in the reactor and deposited in an interim store until a final repository will be available.

Fig. 3: Planned time schedule



DISMANTLING CONDITIONS AT THE FMRB

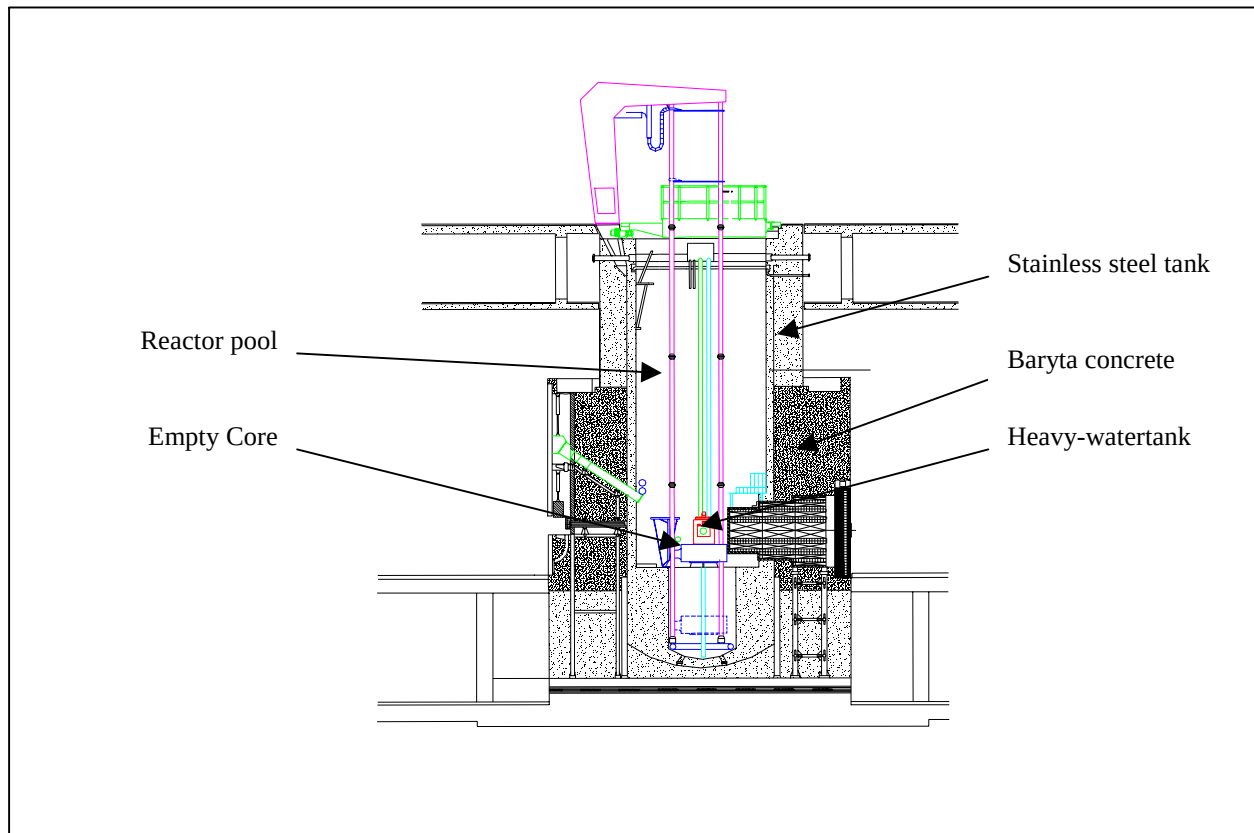
The design of the FMRB, and of other research reactors as well, allows easy dismantling of the reactor body from top to bottom and from the inside to the outside. Only such equipment in the reactor building and machinery hall will be dismantled, whose activation and contamination exceed the limiting values and which are no longer required. All other equipment will be dismantled in a conventional way, after measurements at the plant have furnished uncritical values, or they will be used for conventional purposes, for example the ventilation system, the power supply unit and parts of the fresh water cooling system.

The systems still required for dismantling of the plant, such as:

- power supply
- ventilation systems
- fire alarm and fire-fighting equipment
- water reprocessing plant
- radiation protection instrumentation
- intercommunication system

are in operation or ready for operation.

Fig. 4: Sectional view of the reactor



All experimental set-ups in the experimentation hall have been dismantled and removed from the hall. The graphite from the thermal column will shortly be removed. The beam tubes have been closed with dummy covers, inserts in the beam tubes have been removed.

Fig. 5: View of the emptied experimentation hall



All fuel and absorbing elements have been removed from the reactor pool. The reactor building is free from nuclear fuel. The heavy-water system has been emptied and dried. The water level in the reactor pool has been lowered to a level just above the heavy-water tank.

Almost 100% of the remaining radioactive inventory (about $1 \cdot 10^{12}$ Bq) in the reactor building is in the reactor itself and consists of:

- activation products firmly incorporated in material structures (approx. 99%), and
- contaminations attached to structures in the reactor pool (approx. 1%).

Compared with the situation during reactor operation (approx. $1 \cdot 10^{18}$ Bq), the radioactive inventory at the beginning of the dismantling of parts of the FMRB is thus lower by about 6

orders of magnitude and almost exclusively immobile, as it is firmly incorporated in material structures.

ACTIVATION

Activation of the components in the reactor pool near the former core is low. This is due to the low neutron flux density and the material of which the components are made, which is almost exclusively aluminium. As a result of material contamination, the aluminium internals near the core show the highest activation (about $2 \cdot 10^5$ Bq/g at a mass of only approx. 0,5 Mg). Table 1 shows the radioactivity values of the most important components.

Fig. 6: The sector pool as seen from above

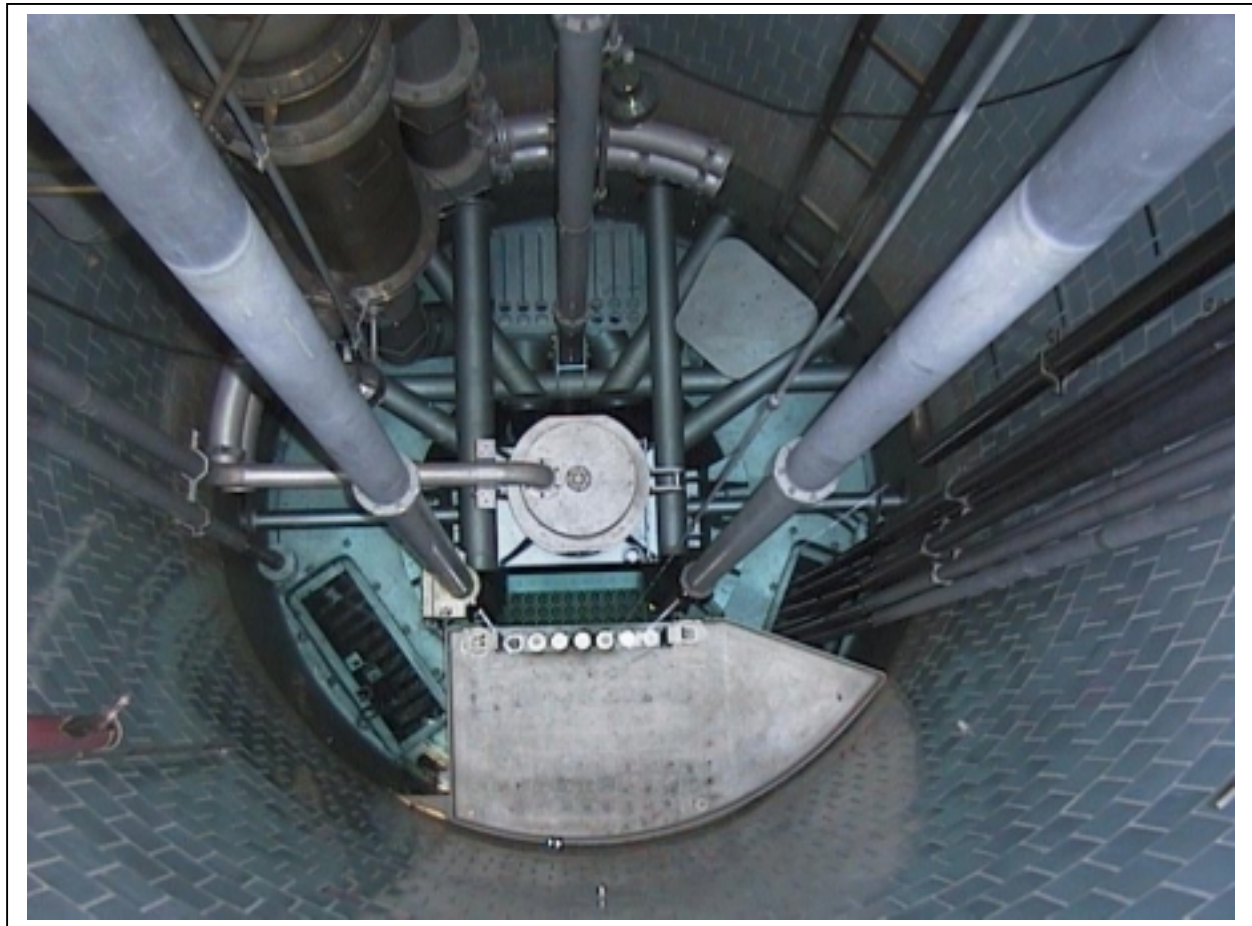


Table 1: Estimated radioactivity values for the most important components of the FMRB in 1998

Component	approx. mean spec. act. in Bq/g	approx. total act. in Bq
Base with water box (aluminium)	$6,7 \cdot 10^4$	$3,5 \cdot 10^{10*}$
Heavy-water tank (aluminium)	$2,0 \cdot 10^5$	$1,1 \cdot 10^{11*}$
Other pool internals (aluminium)	$1,1 \cdot 10^4$	$3,0 \cdot 10^{10*}$
Ceramic and concrete lining near the core	$1,5 \cdot 10^2$	$6,0 \cdot 10^8**$
Reactor tank of steel near the core	$1,5 \cdot 10^1$	$2,5 \cdot 10^7***$
Biological shield near the core (baryta concrete and reinforcement)	1,0	$1,0 \cdot 10^8***$
sum		$1,75 \cdot 10^{11}$

* estimated activity values determined from dose rate measurements related to Co-60
 ** calculated activity values
 *** activity measured

The nuclide vectors of the most important activated materials have been compiled in Table 2 below:

Table 2: Nuclide vectors of the most important activated materials

Nuclide	Activity portion in steel***	Activity portion in aluminium*	Activity portion in standard concrete**	Activity portion in heavy concrete***	Activity portion in lead*
Ca-45	-	-	6	3	-
Mn-54	1	1	-	-	-
Fe-55	91	-	25	26	-
Co-60	8	41	27	21	30
Zn-65	-	25	-	3	3
Ag-110m	-	-	-	-	67
Ba-133	-	-	-	39	-
Eu-152	-	33	39	7	-
Eu-154	-	-	3	1	-

* measured at PTB (activity samples)
 ** calculated
 *** estimated activity portions, determined from activity measurements and calculations

CONTAMINATION

The walls of the reactor pool, the reactor pool internals and the primary coolant circuit in the reactor pool are slightly contaminated. The measured contamination which can be wiped off amounts to maximally 50 Bq/cm^2 . Internal contamination of the secondary coolant circuit can be excluded as its pressure level (geodetic) during operation was higher than that of the primary coolant circuit.

The nuclide vector, which has been determined by gamma spectrometry through evaluation of wiping tests carried out in the upper area of the reactor pool is shown in Table 3, together with the nuclides relevant for the contamination.

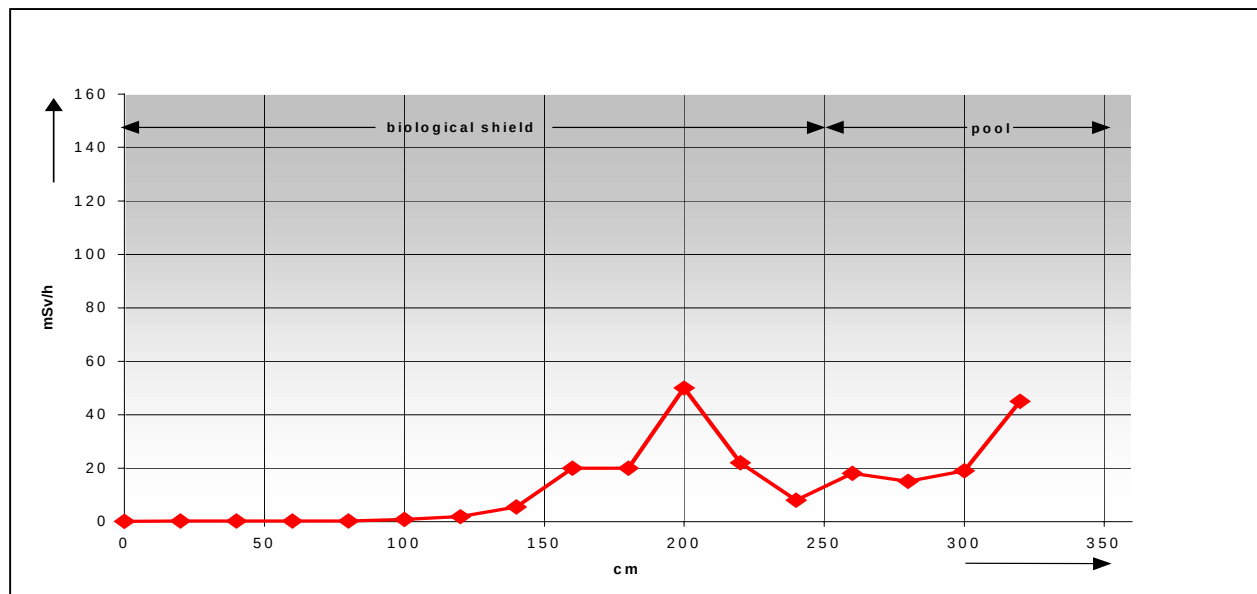
Table 3: Nuclide vector of the nuclides relevant for the contamination

Nuclide	Mn-54	Co-60	Zn-65	Sb-125	Ce-144	Eu-152
Portion in %	1	92	1	1	2	3

DOSE RATES

Because of the openings for the beam tubes, the dose rate is not uniformly distributed through the biological shield and is higher at the holes for the beam tubes and at the activated steel tank

Fig. 7: Dose rates through the biological shield, measured in a radial beam tube. Outer edge of biological shield at 0 cm, the steel tank at 200 cm.



During dismantling, the water level in the reactor pool will be adjusted in such a way that the dose rate on the working stage is about 10 μ Sv/h. According to experience gained in the course of earlier reconstruction work in the reactor pool (renewal of the tiles), this value will be reached at a level of about 2,6 m above the top edge of the former core. The local dose rate in the room above the reactor pool then will amount to less than 5 μ Sv/h. The local dose rate in the experimentation hall is <10 μ Sv/h.

After dismantling of the pool internals, the local dose rate in the reactor pool without water will be approx. 10 $\mu\text{Sv/h}$ in the area which will be entered for the manual removing of the reactor pool lining. The conservative estimate has been based on an activation of the steel tank of 30 Bq/cm³ corresponding to about 15 Bq/g Co-60.

MASSES TO BE DISMOUNTED

The masses to be dismantled during dismantling of parts of the FMRB have been compiled in Tables 4 and 5.

Table 4: Masses to be dismantled in the reactor building

Component	Material	Mass (approx). in Mg
Reactor pool internals (e.g. base, beam tubes)	aluminium	3
Reactor pool internals (e.g. heat exchanger, pipelines)	steel	17
Superstructures of reactor pool (e.g. supporting arm, operating platform)	steel	16
Tank lining near the core	ceramic, standard concrete	15
Reactor tank near the core	steel	4
Biological shield near the core	baryta concrete	310
Thermal column	lead, cadmium, other metals	10
Sum		375

Table 5: Masses to be dismantled in the machinery hall

Component	Material	Mass (approx). in Mg
Storage tank for reactor pool water	steel	24
Radioactive clean-up plant	steel	6
Waste water tank	steel	20
Other parts (small parts, pipelines etc.)	predominantly steel	50
Shielding walls	concrete	110
Sum		210

From today's point of view, approx. 80% of the total mass to be dismantled (about 585 Mg) can be released for utilization or disposal like normal waste.

RADIATION EXPOSURE OF PERSONNEL

A mean effective dose is used as a planning value for the individual person of category A exposed to radiation: of less than 10 mSv per year

To determine the radiation exposure of the personnel (collective dose), the dose contributed by the individual operations was estimated. A collective dose of approx. 35 mSv due to direct exposure will result during dismantling of the FMRB. The following table shows the most important operations and the respective individual doses.

Table 6: Results of the collective dose estimate

Dose package	Collective dose in man mSv (approx.)*			Time in the radiation field in situ in man-hours (approx.)*	
	Dose rate group I	Dose rate group II	Sum	Dose rate group I	Dose rate group II
Preparation of site	-	-	-	-	-
Dismantling above the lowered water level	3	-	3	300	-
Underwater dismantling	4	6	10	400	120
Dismantling of residual parts	7	-	7	700	-
Dismantling of other facilities	10	-	10	1000	-
Addition for other unexpected work	3 (ca. 10 %)	2 (ca. 30 %)	5	300	40
Sum (approx.)	27	8	35	2700	160
Percentage (approx.)	77 %	23 %	100 %	94 %	6 %

* rounded values

- Dose rate group I: 0 - 20 $\mu\text{Sv/h}$; mean local dose rate 10 $\mu\text{Sv/h}$
- Dose rate group II: 20 - 100 $\mu\text{Sv/h}$; mean local dose rate 50 $\mu\text{Sv/h}$

RADIOACTIVE WASTE ARISING

Approx. 120 Mg of radioactive waste with a total activity of about $1 \cdot 10^{12}$ Bq will arise during dismantling of the FMRB.

The contaminated radioactive primary waste is composed of:

- approx. 1 Mg of aluminium
- approx. 14 Mg of steel
- approx. 32 Mg of lead

Sum: approx. 47 Mg

The activated radioactive primary waste is composed of:

- approx. 2 Mg of aluminium
- approx. 9 Mg of steel
- approx. 4 Mg of standard concrete
- approx. 30 Mg of baryta concrete
- approx. 12 Mg of graphite
- approx. 9 Mg of lead
- approx. 4 Mg of other waste (cadmium, beryllium, etc.)

Sum: approx. 70 Mg

The radioactive secondary waste and the waste produced in operation are composed of:

- approx. 5 Mg of solid radioactive waste (e.g. tools, auxiliary means)
- approx. 5 Mg of liquid radioactive waste (e.g. decontamination liquids)
- approx. 3 Mg of resins

Sum: approx. 13 Mg

TECHNIQUES APPLIED FOR DISMANTLING IN A CONTROLLED WAY

Specific boundary conditions must be observed when research reactors are dismantled in a controlled way, e.g. material, nuclides, geometries, spatial conditions. As activation spreads only slightly, it is expedient and commercially efficient in the case of most research reactors to dismantle the activated area only. Moreover, due to the limited space available in research reactors and the very different materials used, the separation techniques which have so far proved their worth in the dismantling of power reactors can be used here only to a limited extent. For this reason, a research project concerning dismantling under these conditions has been initiated, which covers the development, adaptation and qualification of advanced methods, taking also cost minimization aspects into account.

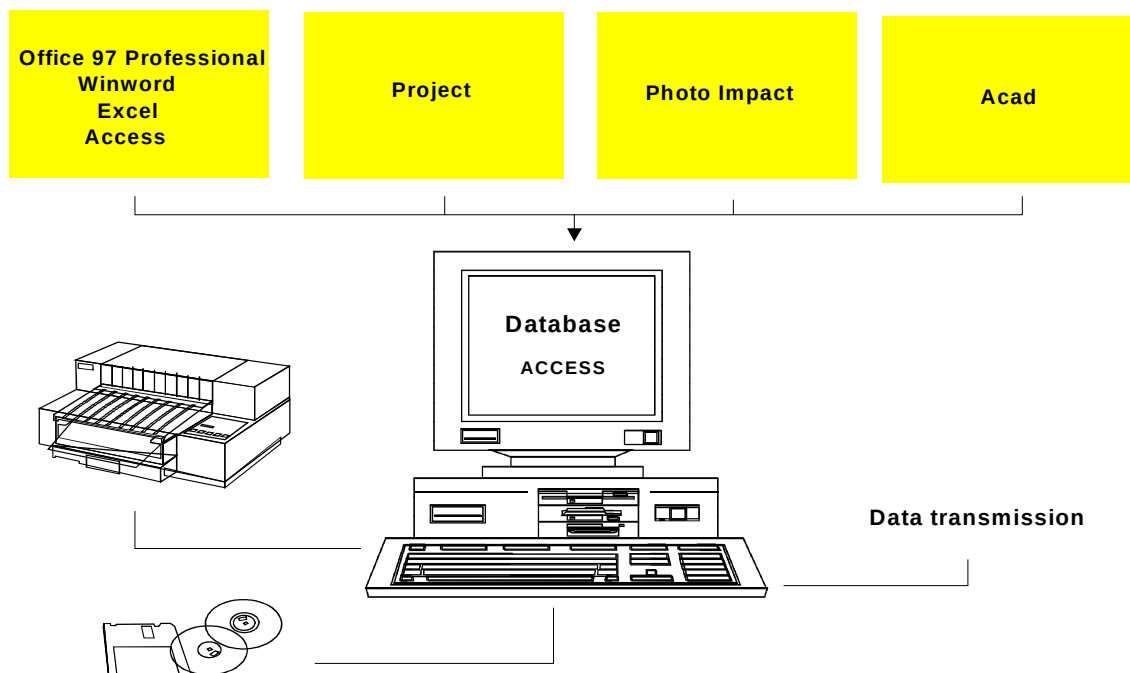
The techniques under consideration are laser cutting techniques using Nd:YAG and CO₂ lasers (under atmospheric conditions and under water, remote-controlled and hand-held), the diode laser (thermoshock decontamination combined with dry-ice cutting techniques), water abrasive suspension jet and stripping by means of dry-ice cutting.

The design of the FMRB, and of other research reactors as well, allows easy dismantling of the reactor body from top to bottom and from the inside to the outside. Only such equipment in the reactor building and machinery hall will be dismantled by special techniques, whose activation and contamination exceed the limiting values and which are no longer required. All other equipment will be dismantled in a conventional way after measurements at the plant have furnished uncritical values, or they will be used for conventional purposes, for example the ventilation system, the power supply unit and parts of the fresh water cooling system.

DATABASE FOR THE DECOMMISSIONING OF RESEARCH REACTORS

The PTB is also developing a computer program named „**Decontamination And Decommissioning Of Research Reactors (DADOR)**“ for the decommissioning of research reactors /4/.

For the dismantling of nuclear power plants, there are various computer programs which allow the costs to be determined, dismantling tools to be selected and activity measurements to be carried out. These programs can be used for research reactors only to a very limited extent, as the activity inventory is considerably lower and as different main nuclides are involved. Moreover, each research reactor has been constructed according to a specific concept tailored to the special tasks to be carried out. Use of many special materials such as, for example, graphite, titanium, beryllium, molybdenum, etc., requires special measures to be taken for dismantling and disposal. It is, therefore, recommendable to establish an individual information system for the decommissioning of a research reactor, which covers the whole process - from the planning phase to the release measurement of the plant - and which runs on commercial computers using commercial software.



This system is intended to support the project management in its tasks and decisions, to describe the current state of the activities and of the plant, to list the individual work packages according to staff and costs, and to take the aspects of radiation protection and nuclear waste management into account. This will allow a comparison to be made with other decommissioning activities and support to be given for decommissioning activities to be carried out in the future. The program is divided into seven work packages which are listed in Table 7.

I. Development and establishment of a data-base-assisted information system

- exchange with other data bases
- access to other data bases
- definition of the interfaces
- maintenance of data

II. Determination of the actual state of the research reactor

- plant description (reactor type, plant-specific characteristics, history, power, etc.)
- plant marking (plant identification code)
- determination of the plant's activity inventory
- special materials
- masses
- origin (place of installation)
- operating time

III. Planning and determination of costs

- costs of nuclear waste management
- one's own costs
- costs of third parties
- investment costs

IV. Planning of decommissioning

- (conditions for starting the action)

- approvals
- directives
- manual for dismantling, safety report
- decommissioning variant
- dismantling
- reports
- staff organization

V. Nuclear waste management

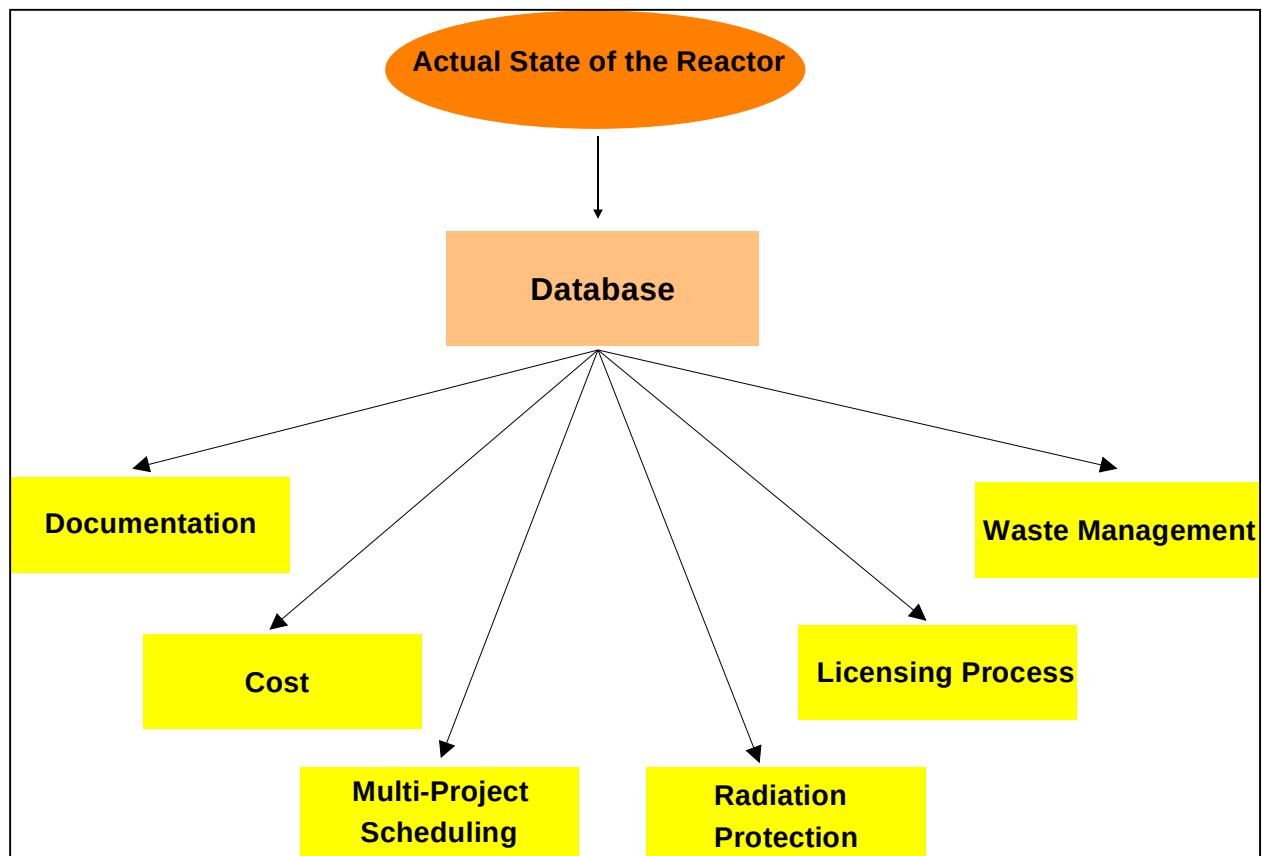
- definition and listing of all plant components
 - material flow (waste follow-up system)
 - material treatment (decontamination, dismantling procedure)
 - final disposal/storage (conditioning, transport)

VI. Radiation protection

- determination of the dose rates
- exposure of personnel
- emission planning (monitoring of the environment, amounts emitted)
- measuring and monitoring programs and techniques
- decontamination
- sampling program
- program of release measurements
- staff organization

The program takes account of the fact that research reactors must generally be decommissioned with only a few staff members involved, as it

- is tailored to the special features of research reactors
 - allows flexible handling, with due regard to practice
 - can be used in situ and provides comprehensive and quick information about the actual state at any time
- optimizes the assignment of labour and the costs.



SUMMARY

The effort and expense to be spent on the decommissioning and dismantling of a research reactor and required to meet the licensing requirements are considerably lower than those for power reactors.

This is essentially due to the very low risk potential, the low radioactivity and the small mass of the waste arising. Accordingly, the effort and outlay required to draw up the application documents are low compared with nuclear power plants.

The license for the decommissioning and dismantling of the FMRB is applied for with the aim of carrying out a licensing procedure tailored to research reactors, which might serve as a guidance for the future decommissioning of research reactors and which takes into account in both technical and legal respect the requirements which are clearly lower than in the case of power reactor decommissioning.

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