FRJ-1 Research Reactor (MERLIN) Makes Way for a „Green Field“ - Milestones on the Road to Paradise Regained

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ABSTRACT

This report describes the previous path of the research reactor FRJ-1 (MERLIN) from shutdown to "green field site", whereby primary focus is placed on milestones representing distinctive phases of dismantling. However, not only the milestones, but also the stumbling blocks are worth mentioning, because even negative events are painful and therefore provide good examples of what not to do in future projects.

Dismantling of FRJ-1 began in 1995 with rather unspectacular demolition of the conventional air cooling system. Nevertheless, this was a significant milestone because it marked the beginning of the nuclear decommissioning era for Research Center Jülich. From this time on the most significant milestones along the path to "green field site" are represented by:

- ✓ Demolishing the system circuits and removal of experimental equipment
- ✓ Removal of built-in equipment in the reactor tank
- ✓ Demolition of the reactor block
- ✓ Decontamination and clearance measurement of the reactor building followed by dismissal from the German Atomic Energy Act.
- ✓ Conventional demolition of the reactor hall with the objective of converting to "green field site"

These steps are explained below in greater or less detail depending on their degree of controversy and interest. At the time this report is published, the reactor building will be dismissed from the German Atomic Energy Act. The last step in conventional demolition should also be completed at this time according to the original planning. However this was prevented by one of the many stumbling blocks on the way to success. Nevertheless it is assumed at the present time that this step will also be concluded before the middle of 2008.

INTRODUCTION

The FRJ-1 (Fig. 1) was a light water moderated and cooled, pool type reactor of British design, which was last operated at a thermal power of 10 MW.

The FRJ-1 was the first of the two reactors in the Jülich Research Center to be ultimately shut down in 1985 after 21 years of operation. Even during the year in which it was shut down, an important step was taken by removing the fuel elements from the system. After most of the experiments had finally been dismantled, the FRJ-1 was quasi in a state of "safe enclosure" for approximately 10 years. In 1995 the "safe enclosure" was finally discontinued. The reactor was then dismantled step by step within the scope of 4 partial approvals and is now ready to be discharged from the German Atomic Energy Act. Dismantling of FRJ-1 (MERLIN) was accompanied by many highlights, as well as many setbacks. Nevertheless, it has ultimately resulted in success with a "happy ending" within reach. Conventional dismantling of the reactor building will present a final highlight to the previous success story according to present planning, particularly when a UFO with diameter of

30 m rises from the reactor building and lands gently on the green meadow. This will ring out the end of an era, the era of the "**M**EDIUM **E**NERGY **R**ESEARCH **L**IGHT WATER MODERATED **I**NDUSTRIAL **N**UCLEAR REACTOR" or simply MERLIN.

Fig. 1. Research reactor FRJ-1 (MERLIN)

STEP BY STEP TO "GREEN FIELD SITE"

Many small steps were necessary, and still are required, from the first demolition phase to the last shovelful of dirt to plant a tree along the way "back to paradise". This expression, which also represents part of the title, may appear polemic, however in view of the current situation in Germany there certainly are voices of the opinion that the fall of the last nuclear bastion does, in fact, represent a return to paradise. In the truest sense of the word, because there was no electricity in paradise either. However these small steps lead to a handful of milestones, marking the path. This will be treated in the report below.

First Milestone – Air Cooling System

After 7 years of "Big Sleep" the research center again became aware of its reactor on a cool day in February 1992. On the occasion of a local inspection it was ascertained that the structural stability of the air cooling system was endangered due to corrosion on supporting parts of the steel construction. This provided the final impetus for starting to dismantle the FRJ-1. Who knows; perhaps it would still continue its "Sleeping Beauty" sleep if it had not been woken up by this discovery. However, once awakened, things took their course. Without delay an application for demolishing the air cooling system was submitted in May 1992 and approval pursuant to the German Atomic Energy Act was granted in June of 1995. The **1st Milestone**, which ultimately rang in the nuclear decommissioning era for Research Center Jülich, was then culminated by rather unspectacular demolition of the conventional air cooling system, which was also concluded in

1995. The air cooling system with a total weight of approx. 350 Mg was ultimately disposed of as scrap through commercial channels.

Second Milestone – System Circuit and Experimental Equipment

The second approval application was submitted in April 1996. In concrete terms this covered, among other things, shutdown and dismantling of system parts no longer required, specifically the system circuits and the remaining experimental equipment. In July of 1997 the appropriate approval was granted, finally allowing removal of the first contaminated and/or activated parts of the actual reactor. By the end of 1998 the entire secondary cooling system and the major part of the primary cooling system had been dismantled. Moreover the remaining experimental equipment still present (Fig. 2), including an in-core irradiation device designed as a pneumatic tube conveyer, was dismantled and disposed of. All in all nearly 65 Mg of contaminated and/or activated material as well as approx. 70 Mg of material measured as contamination-free was removed. The contaminated and/or activated parts of the reactor were surrendered to the decontamination department of Research Center Jülich. Reactor parts determined to be free of contamination were ultimately disposed of conventionally (e.g. scrap recycling, dump).

Fig. 2. Removal of experimental plug

Separation and removal of the lifelines in the form of the system circuits led to infrastructural isolation of the reactor block, removal of the experimental equipment to exposure of the heart of the reactor block, the previous reactor core. Conclusion of these activities therefore set the **2nd milestone**, whose completion opened the way to disembowelment of the inner reactor block in a virtually surgical manner.

Third Milestone – Removal of Equipment Installed Inside Reactor Tank

In September 1999 the next approval application was submitted to cover the components relevant for previous operation of the reactor as well as the components which became visible inside the reactor block only after removal of the experimental equipment. This approval, declared as a supplement to the previous application, primarily covered removal of the equipment installed inside the reactor tank. The equipment installed inside the reactor tank consisted primarily of components in the core area of the reactor block, which served to accommodate the fuel elements and optimize the coolant flow and neutron flow. This application was approved in April 2000 with the corresponding notice of approval.

Particular problems with a decisive effect on removal of the equipment installed in the reactor tank included, on the one hand the limited space in the area of the core and, on the other, the unfavorable methods of fastening and connecting the components. The major part of the components were assembled and installed with slotted screws during the assembly phase, at which time the radioactivity was of no significance whatsoever. A particular challenge was the fact that these screws were generally installed perpendicular to the viewing direction. The budding idea of simply ignoring the screws and disposing of them together with the components was quickly discarded. Although the fact that the major part of the components consisted of aluminum made this idea very attractive in terms of technical disassembly, its implementation would have led to a significant increase in the volume of highly radioactive waste. The major part of the activity present was concentrated specifically on the stainless steel nuts and bolts, which made up only a small part in term of volume. It was therefore necessary to separate the aluminum components from the stainless steel connecting elements with surgical precision to minimize the highly radioactive waste.

Due to the high radioactivity of the components installed in the core remote handling under water was required for disassembly. The most inaccessible screwed connection to be undone was approx. 6 m below the surface of the water. To accomplish this work it was necessary to design and produce various special tools for screwing, milling and sawing, which had to be adapted to the marginal conditions present. Visualization of the underwater disassembly area was realized with the aid of an 8 mm video endoscope. Fig. 3 shows the situation at the intermediate floor of the tank during the phase of unscrewing the slotted screws which were used to fix the components of the tank internals. Fig. 4 shows the view through the video endoscope and therefore the real situation in the reactor tank.

Fig. 3. Unscrewing the slotted screws in
Fig. 4. View through the video endoscope
reactor tank

In some cases it was not possible to undo the screws and they were damaged in the attempt (Fig. 5).

Fig. 5. Damaged screw in the reactor tank

For such situations it was necessary to design and construct a special milling tool (Fig. 6). The video endoscope was also excellently suited for positioning the tool for the milling procedure. By using the milling tool, we were able also to separate the high-activated screws made of stainless steel from the low-activated aluminum components (Fig. 7).

Fig. 6 Milling tool for separating the screws

Fig. 7 Drilled-out part

Individual reactor components had to be cut underwater inside the reactor tank. On the one hand, this step served to disassemble components welded onto the reactor tank and to adapt the removed reactor components to the waste containers used. On the other hand, this served to create manipulation openings required for the further removal of the reactor tank internals. Mechanical cutting was selected for the corresponding demolition work and all processes had to be remote-controlled down to a depth of 6 m. For the existing aluminum thicknesses of up to 100 mm for the core support plate, a pneumatic compass saw was upgraded for underwater applications (Fig. 8, 9).

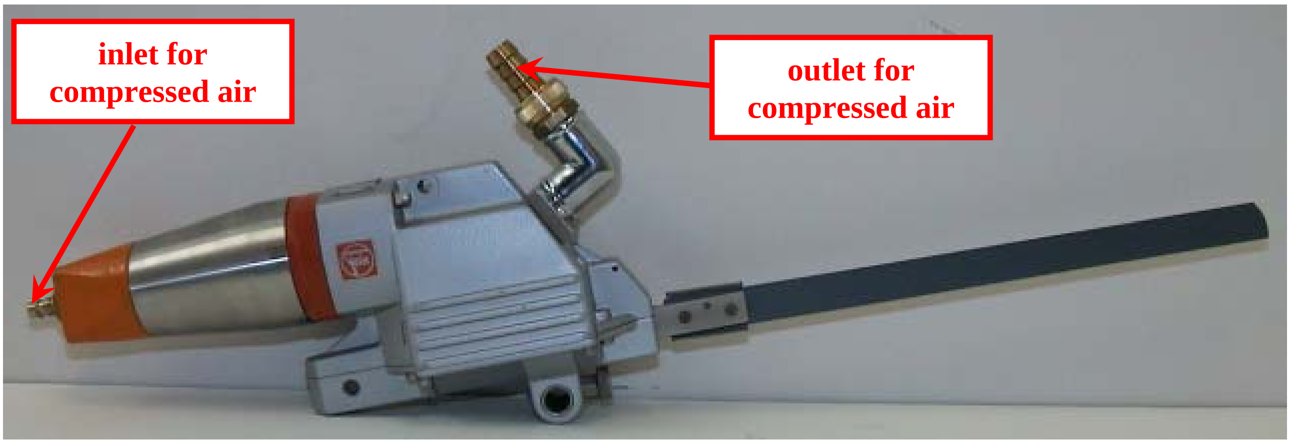

Fig. 8. Pneumatic compass saw upgraded for underwater applications

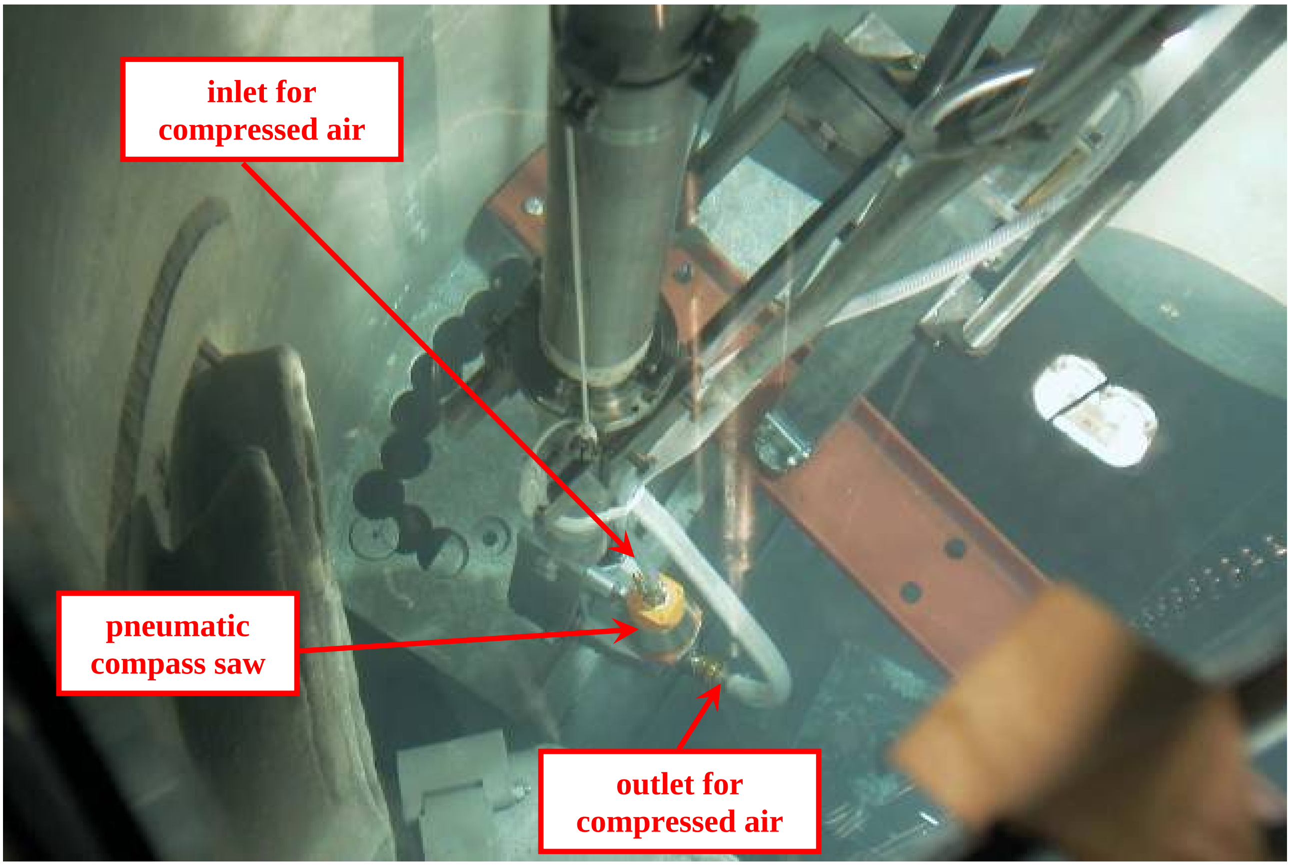

Fig. 9. Removal of equipment installed in reactor tank – sawing underwater

Construction of a mock-up proved to be particularly efficient for these comprehensive and complex problems. With this model it was possible to simulate the equipment installed in the reactor tank and the special removal conditions on a scale of 1:1 (Fig. 10 - 13).

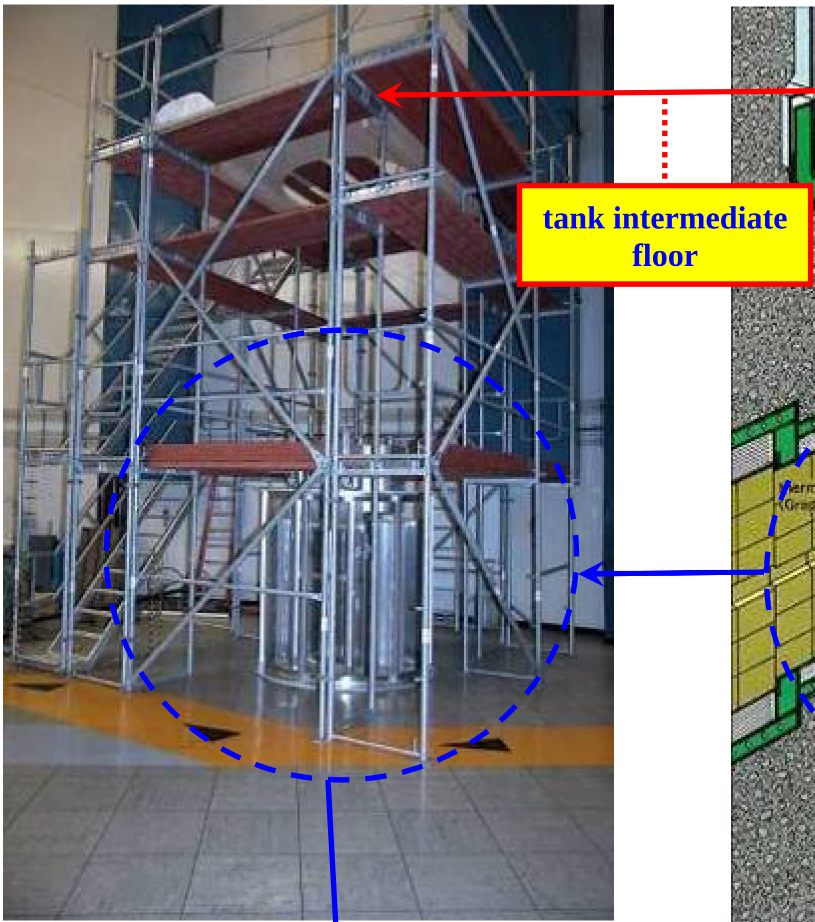

Fig. 10 Simulation of the tank intermediate floor

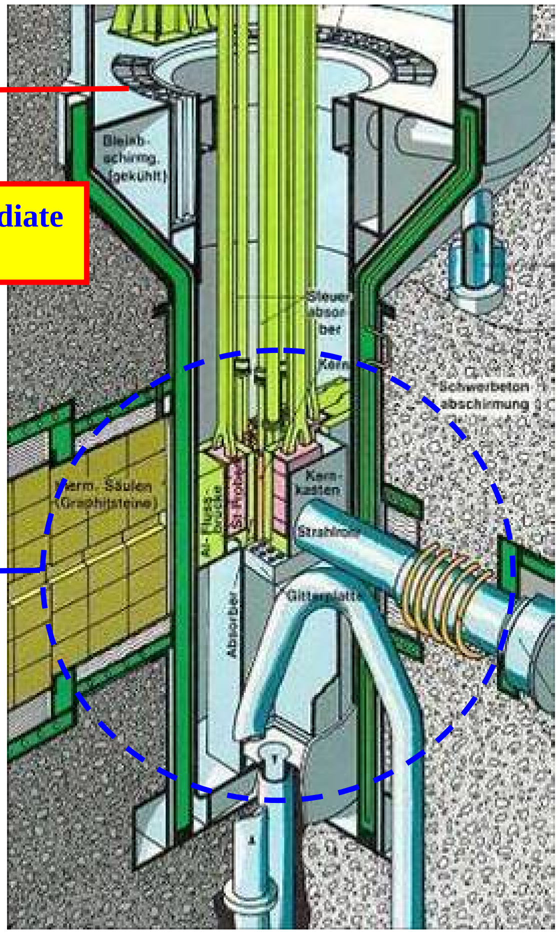

Fig. 11 Diagram of the reactor core

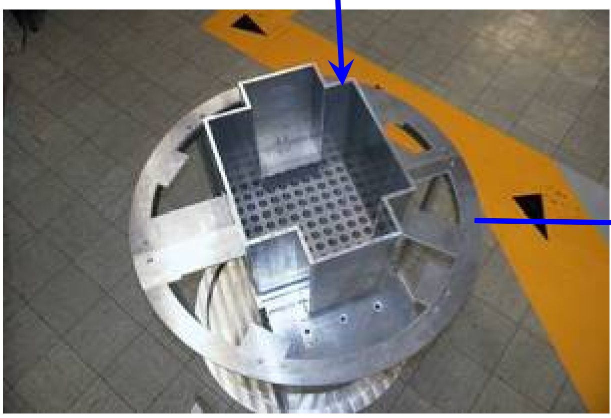

Fig. 12 Mock-up of the reactor tank internals on a 1:1 scale

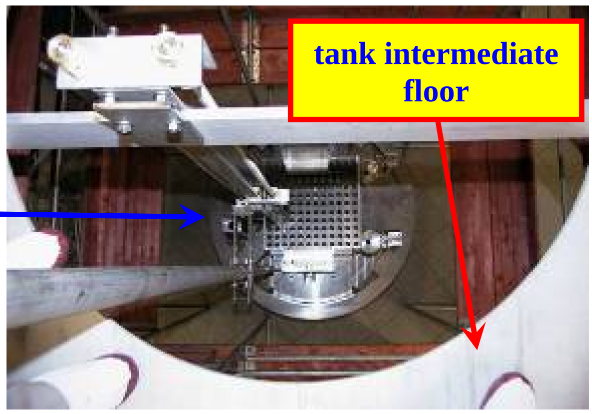

Fig. 13 View from the top of the mock-up

Removal of the equipment in the reactor tank yielded approx. 2.5 Mg of removed parts with a total radioactivity of approx. 8 x 10^{11} Bq, which were surrendered to the decontamination department of Research Center Jülich.

Disassembly of the equipment installed in the reactor tank was concluded at the end of 2001. After reaching this **3rd milestone** the way was then clear to drain the reactor block and start work on the block itself.

Fourth Milestone – Reactor Block

The application for dismantling the reactor block was submitted in November 2000. This was the central component containing the core and the primary experimental equipment required for performing irradiation experiments. The approval notification for dismantling the reactor block was granted at the end of July 2001.

With a total height of approx. 11 m, the block had the form of an octagon with a distance of 5.65 m between the parallel surfaces. The main mass of the reactor block consisted of the biological shield surrounded by steel liners on the inside and outside. In the former core area the biological shield had a thickness of approx. 1.80 m and consisted of heavy concrete with a density of approx. 4,200 kg/m^3. In the upper area with a thickness of approx. 1 m, iron-reinforced normal concrete with a density of 2,350 kg/m^3 was used. Moreover, a thermal shield of aluminum-encased lead segments with a thickness of approx. 100 mm was present in the core area. Various experimental devices were integrated into the reactor block at the height of the former reactor core for performing experiments. These consisted primarily of aluminum, lead and steel. All in all there were 10 horizontal beam tubes and 2 thermal columns.

Dismantling of the reactor block was started in October 2001. The primary tools for this work consisted of remote-controlled disassembly robots with rock chisels (Fig. 14). Preliminary tests performed to determine the radiological situation in the reactor block with diamond tools ruled out the use of diamond tools for disassembly of the entire reactor block from the very beginning. The composition of the heavy concrete which contained magnetite with nail tip shot additive proved too much for the diamonds. The design of an adapted sawing device for disassembly of the metallic components in the reactor block (inner and outer steel liner, aluminum reactor tank, thermal shield made of lead) also proved to be too expensive and time-consuming. Moreover continuous use of such a tool would have resulted in the intervention time for the personnel in the radiation field being unreasonably high (particularly for positioning the device). The disassembly robot therefore proved to be the ultimate tool for all metal and concrete structures.

The entire reactor block was encased and the encased area evacuated by two ventilation systems at a total flow rate of 12,000 m^3/h, to prevent the escape of contamination. These systems ensured positive ventilation flow from the reactor hall into the casing. In addition a humidifying unit was used to directly prevent any contaminated dust from spreading during demolition of the concrete structures.

The major part of the material resulting from demolition was packed in 200 l drums. Drums with structures anticipated to be classified as radiation-free were measured preferably with a radiation classification measuring system using the total gamma measurement principle. Disassembly of the reactor block yielded a total of approx. 1.000 Mg of material primarily in the form of heavy concrete, normal concrete, aluminum, steel and lead. At least half of the material removed was classified as non-radioactive without limitations, allowing conventional disposal. The other half was surrendered to the decontamination department of the Nuclear Service Department for conditioning (including later clearance measurement) or for storage.

Fig. 14. Disassembly of the biological shield with disassembly robots and rock chisel

The maximum specific radioactivity of the demolished structures was approx. 1.0 E+07 Bq/g, the maximum contact dose rate during dismantling of the reactor block was approx. 420 mSv/h. Maximum dose rates of approx. 160 mSv/h were measured on the containers filled with wastes, particularly on containers filled with material from the core area. The dose rate in the working area of the personnel during disassembly of the core structures amounted to approx. 30 μSv/h on the average with maximum values of up to 80 μSv/h.

After completion of disassembly of the reactor block 99% of the artificial radioactivity from the reactor building had vanished. The status was achieved by the end of 2003. Conclusion of dismantling was therefore not only the **4th milestone**, but also **the** milestone, which ultimately initiated the search for the last remaining artificial nuclides.

Fifth Milestone – Decontamination and Clearance Measurement of Reactor Building

In May of 2003 the application was submitted for clearance measurement of the reactor hall with the following dismissal from the scope of supervision under the German Atomic Energy Act. This application was approved in November 2004 by issuing the corresponding approval notification.

Immediately after conclusion of dismantling the reactor block at the beginning of 2004 preparation measures were started for clearance measurement of the reactor building. For this purpose utilities no longer required such as electrical facilities, control equipment and supply and disposal lines for compressed air, fresh and waste water and ventilation as well as steel constructions no longer required (e.g. reactor control building) were first torn down and disposed of. The work performed for this purpose provided the required access to wall, ceilings and floors necessary for performing the subsequent decontamination measures. In the course of the decontamination work started in March 2005, it was quickly ascertained that significant changes would be necessary to the originally planned procedures. The original planning for clearance measurement of the reactor building assumed that the standing structure of the building could be measured for clearance after extensive decontamination of the surfaces. A significant stumbling block in this case proved to be the contamination which had penetrated deep into the wall and ceiling structures, which ultimately made it necessary to reject the original plan. This development led to considerably more extensive decontamination measures. In summary it can be noted that, due to this unexpected development, it was necessary to demolish an additional, unplanned 480 m³ of concrete in the form of supporting walls and ceilings. It was not possible to simply cut away contaminated structural substance, because this would have weakened the supporting walls to an unacceptable degree.

In the first step the wall and ceiling structures to be torn down were cleanly separated from the remaining building structure with the aid of diamond cutting saws (cable and disk saws). Over 90 heavy duty supports were positioned in the area to be torn down to secure the ceiling areas from caving in. The second step consisted of the actual demolition of the affected wall and ceiling structures. The equipment used here was the familiar equipment which had already proven itself in tearing down the reactor block. This equipment primarily included demolition robots with rock chisels (Fig. 15), ventilation systems and clearance measurement device. Including concept, approval and execution planning as well as the times required for expert reports and official approval, the measures for expanded decontamination required over one year. It was not possible to continue the decontamination work, which was interrupted by this unexpected discovery the middle of 2005, until November 2006. Finally in February of 2007 it was possible to finish complete decontamination of the FRJ-1 reactor building. The work for clearance measurement in the reactor building was then started at this time.

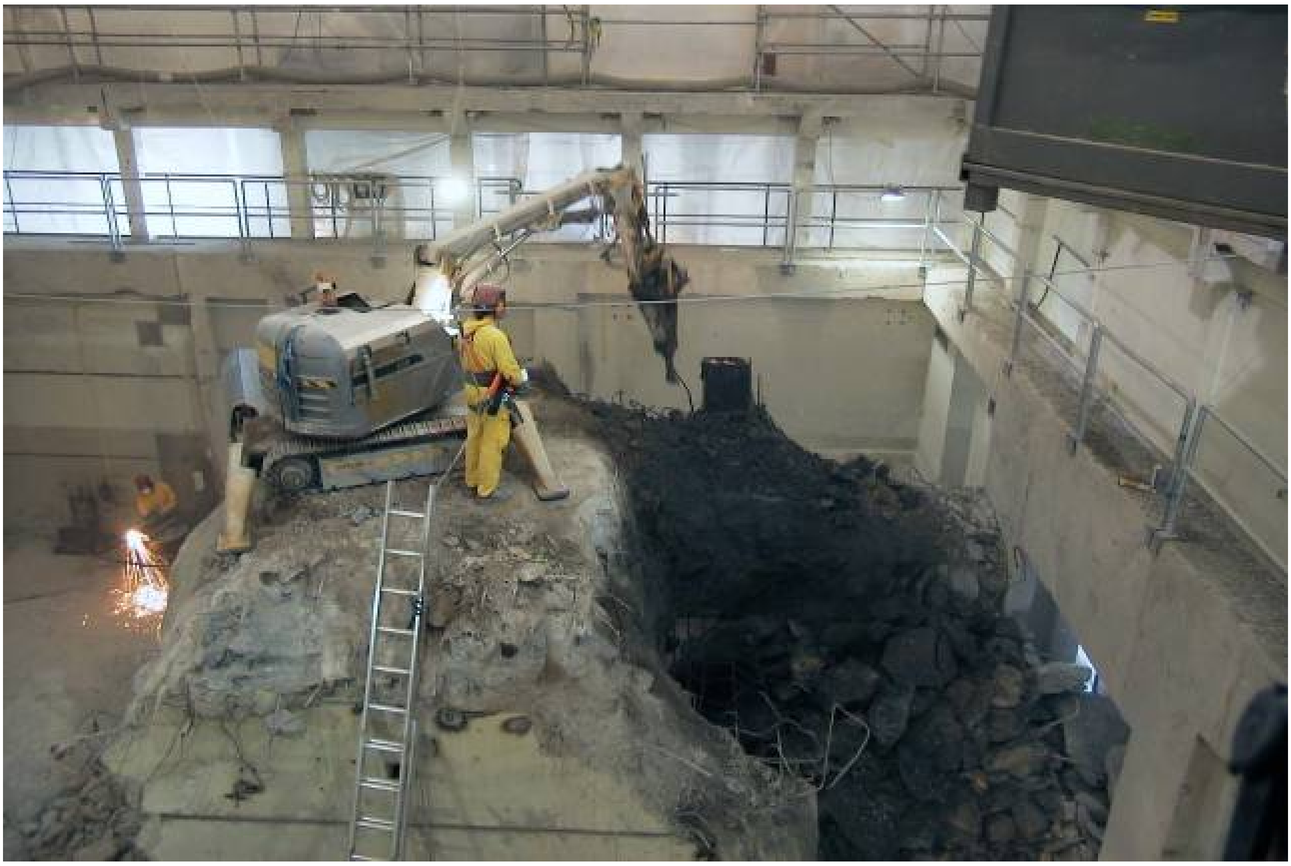

Fig. 15. Demolition of intermediate ceilings and walls – expanded decontamination

A significant part of the clearance measurement activities consisted of a graduated, consistent concept of retreat to ensure that areas already measured for clearance would not be recontaminated.

The quintessence of the retreat concept was to ensure a directed flow of air. For this purpose it was frequently necessary to construct casings to create closed room structures to ensure directed flow. Moreover it was also necessary in many cases to provide for additional openings for incoming air, overflow and exhaust. In summary it can be noted that the ventilation planned and ultimately realized within the course of the clearance measurement work was consistent, because the air always flowed in through the rooms in the sequence in which the work was to be accomplished. This ensured that recontamination along this path was not possible.

The clearance measurement work in the reactor building with its approx. 30 m high reactor dome proved to be a particular problem. Demolition of additional wall and ceiling structures required due to the contamination quite literally pulled the rug out from under the personnel´s feet. The elevating platforms available for the measurement work with lifting heights of up to 18 m were no longer sufficient. For this reason it was necessary to install a suspended scaffold on the 10 Mg hall crane from FRJ-1, which could be reached from one of the existing elevating platforms (Fig. 16). This suspended scaffold proved to be extremely effective for the measurement work in the reactor dome and on the crane bridge.

Fig. 16. Suspended scaffold on 10 Mg hall crane

Clearance measurement in the reactor building including check measurements by the officially appointed expert (Fig. 17, 18) was completed in the middle of September 2007. Dismissal of the reactor building from the supervisory range of the German Atomic Energy Act was applied for on 21st of September 2007 in a communication to the responsible nuclear licensing authorities.

Fig. 17. Clearance measurement of the reactor dome

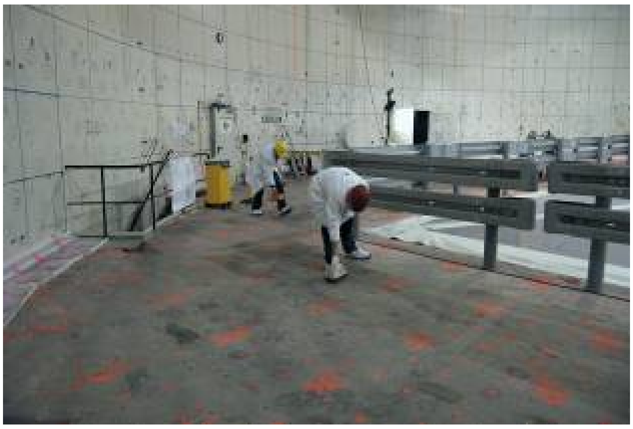

Fig. 18. Clearance Measurement of floors and walls

Conclusion of the clearance measurement work on FRJ-1 (MERLIN) represents the **5th milestone** on the way to a “green field site”. Official dismissal of the reactor hall from supervision in conformance with the German Atomic Energy Act by the nuclear licensing authorities is all that is left to tackle for the last milestone of conventional demolition of the reactor building.

CONCLUSIONS

For the dismantling of reactor components, especially of the reactor tank internals, a lot of special tools are necessary. Reasons for this may be cramped conditions, the need to remove, dismantle and handle components underwater and/or to remove, dismantle and handle components considering defined distances. In the case of the reactor tank internals of the FRJ-1 reactor all the above-mentioned reasons were the case. According to a market analysis that was made at that time none of the required tools was available. Therefore we had to construct these special tools ourselves. Besides this an important realization was the fact that even with regard to research reactors most special tools are quite individual. As a rule, every research reactor has a unique design. Therefore special tools made for one research reactor cannot normally be adapted to a different reactor.

The construction of a mock-up proved to be very important. In addition to its function as a training device for remote-controlled removal as well as a testing apparatus for testing and modifying the special tools, the mock-up also served the officially appointed expert for testing and approval of the tools and operating procedures.

With regard to the dismantling of the reactor block of the FRJ-1, it became apparent that increased use of the chisel technique combined with the remote-controlled dismantling excavator was of great benefit. The advantages of using the chisel were, in particular, minimization of the intervention time spent by the personnel in the radiation field, and also increased effectiveness of the dismantling work. Using this technique it was not only possible to effectively dismantle the heavy concrete but also the aluminum, lead and steel components.

In order to avoid spreading contamination the entire region to be dismantled was encased at the start of dismantling work. In combination with the installed ventilation systems and the moistening apparatus that was used during the dismantling activities at the reactor block these measures proved very effective. A spread of contamination into regions outside the casing was completely prevented.

As part of the decontamination and clearance measurement activities, unconventional ideas were necessary, too. An excellent example is the scaffolding that was constructed for the 10 Mg hall crane as auxiliary equipment for the decontamination and clearance measurement of crane and reactor dome.

Besides this, important experience was gathered during the decontamination and clearance measurement phase, namely that contamination is ubiquitous. The presumption that there is not so much deep penetration of contamination in walls and ceilings was radically wrong. The result was the additional dismantling of 480 m^3 concrete. Besides this negative experience essentially positive experience was also gained. Good preparatory and decontamination work leads to a short clearance measurement time. The whole reactor hall was finally measured for clearance in only 4 months. This involved more than 100,000 measuring points, of which 30,000 were documented.

OUTLOOK OR "THE LAST MILESTONE"

Actually the "Happy Ending" was planned for 2007, but then things worked out differently. And technical or financial problems were no what prevented us from reaching the anticipated target, but rather purely formal, commercial aspects. It is not intended to go into detail on this here. But we should note that the bidding process for conventional dismantling of a building skeleton caused more confusion than most of the previous bidding processes for dismantling the nuclear system parts. We were ultimately successful in concluding the bidding process satisfactorily. The contractor has been chosen and his plans allow us to anticipate a final highlight in the dismantling of FRJ-1 (MERLIN). If everything runs according to plan, a UFO will rise from the body of the FRJ-1 reactor hall and gently land next to it on the green meadow at the beginning of 2008. The planning specifically provides for lifting the reactor dome with a diameter of 30 m in its entirety from the building structure. Heavy duty cranes with corresponding hoisting capacities will serve as the drive. The cameras are already focused, because no one wants to miss this. Following this highlight the remaining building structure including the foundation will be torn down and disposed of. By the middle of 2008 a "green field site" will be found where once a reactor stood, and, if there is enough money left, perhaps a tree may even be planted? This would at least be a distinctive symbol for the **last**, **6th milestone** in dismantling of the FRJ-1 Research Reactor (MERLIN).