BIOLOGICAL SHIELD DISMANTLEMENT AT VAK KAHL

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ABSTRACT

This paper describes the demolition of VAK's biological shield. VAK has been the first German nuclear reactor and the first German BWR. It was operate to generate electric power as well as to test different types of fuel elements including MOX. VAK is a General Electric design with an electric power output of 16 MW. The reactor was erected between 1958 and 1960 and first became critical in 1961. It was then operated for 25 years and was finally shut down in 1985. By this time the site had fed 2000 GWh of electric power into the grid. In 1988 the regulatory authorities agreed to start dismantling work. Decommissioning will be finished by 2006.

INTRODUCTION

Decommissioning of VAK is performed in four phases, each of these needing a separate license. The 1st license achieved in 1988 covered the general permission for decommissioning as well as the clearance of the turbine hall from all systems. The 2nd license included all contaminated systems inside the reactor building. Dismantlement of activated components like the reactor vessel and the biological shield was part of the 3rd license. The 4th and last license achieved in 2000 covers the dismantlement of all remaining systems, the decontamination and pull down of buildings and the release from the atomic regulations.

This paper describes the dismantlement of the biological shield which started in autumn 2002 and which has been completed by midth of 2003.

BIOLOGICAL SHIELD STRUCTURE

VAK's biological shield is a concrete monoblock with an inner diameter between 3 meters and 5.5 meters. Its vertical extension is roughly 11 meters. With respect to the outside ground level most of the shield lies beneath zero level, the core center being at – 4.5 meters. VAK's biological shield ist completely integrated into the massive reactor building walls. There are no annular aisles around the shield. Only at a few locations direct access to the rear side of the shield is provided. It is this special shield construction which later on induced the decision to demolish the shield from its inside to the outside in contrast to the preferred direction at other reactors.

Figure 1 shows a cross section of the reactor building with the embedded biological shield.

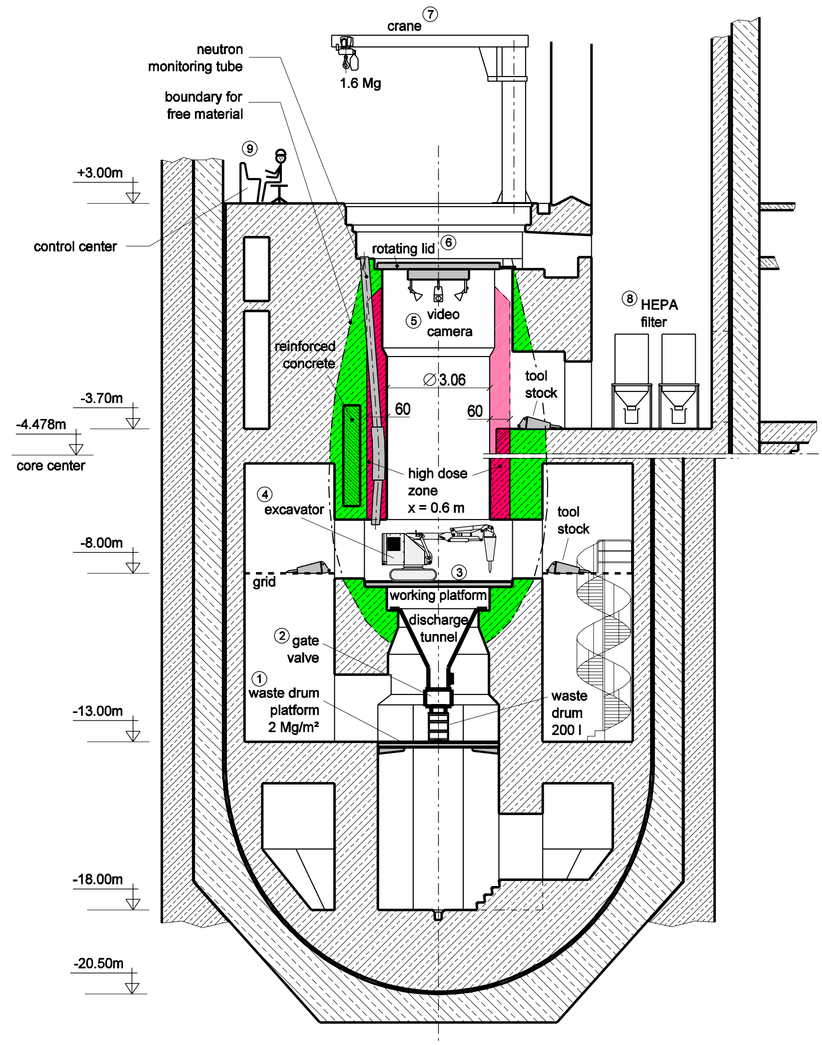

Fig. 1 Biological shield cross section

Several layers of reinforcement are embedded into the inner shield zone expanding along the vertical axis. Between these layers pipework of the active shield cooling system is integrated. The cooling tubes wind around the shield cylinder like meander tracks. Finally 9 pipes for neutron monitors are inserted into the shield. Along the former reactor core the neutron monitor pipes are shielded by lead cylinders.

In sum 50 tons of iron and other metals are embedded into the shield. The rear zone of the biological shield includes in about 1 m depth a heavy duty concrete body which surrounds the core cavity cylindrically.

RADIOLOGICAL SITUATION

After dismantlement of the reactor vessel and of the primary cooling system, free access to the biological shield was possible from the vessel cavity. Planning of shield dismantlement started with radiological shield characterization. Dose rate measurements were performed and probes were taken from different layers inside the shield wall to analyze the activation profile. The main radio isotopes found were Co-60, Eu-152, H-3 and Fe-55.

The highest dose rate was measured as one may expect in the former core region. Dose rates there varied from 4 to 5 mSv/h. In view of this situation it was later on decided to dismantle the shield by remote operated equipment. The general strategy for demolishing VAK's concrete structures is to remove all activated and contaminated material and finally pull down the edifices under conventional conditions. Concerning the dismantlement of the biological shield this not only is a question of the right technology but one also has to consider the amount of material which is dug out just to keep the amount of radioactive waste as low as possible. The activation profile inside the shield wall had therefore to be examined thoroughly. This profile finally represents the boundary between free material, which can remain in place and radioactive material which must be excavated.

Due to National legislation and release requirements nuclear material disposal in Germany is ruled by a set of limit values. With respect to building material the legal regulations distinguish between radioactive material and free material. Radioactive material must be disposed in a nuclear repository. Free material instead is subdivided into such material which can be released without any restrictions and such material which can be released with certain restrictions.

Restricted material usually may be embedded into public landfills or may be disposed into former mines. In both cases it must be guaranteed that the annual dose for a person working at such a site is less than 10 µSv. The clearance values of the main isotopes present in VAK's shield material are listed below in table I.

Table I Release limit values for building material

Isotope	Activity Concentration Bq/g		
	unrestricted release	restricted release	waste
Co-60	0.1	4.0	> 4
Eu-152	0.2	8.0	> 8
H-3	1E3	1E3	> 1E3
Fe-55	2E2	1E4	> 1E4

In case that there is a mixture of different nuclides, the sum of the relative nuclide concentrations must be less than 1. For unrestricted release of the VAK shield material this rule implies that the following equation is fullfilled:

$$\frac{C\ (Co\text{-}60)}{0.1} + \frac{C\ (Eu\text{-}152)}{0.2} + \frac{C\ (H\text{-}3)}{1E3} + \frac{C\ (Fe\text{-}55)}{1E4} < 1 \qquad \text{(Eq. 1)}$$

In Eq. 1 C (Co-60) is the Co-60 activity concentration in Bq/g, and the denominator represents the unrestricted release value of table I for Co-60. The other isotopes are handled in a similar way. In practice this means that each of the isotopes must have a concentration which ist less than the corresponding limit value. With respect to these legal requirements the activation profile inside the shield wall was analyzed prior to dismantlement. In Fig. 1 the contours of the differently activated material zones are roughly illustrated. The inner sphere which is radioactive waste material and which therefore shows the highest dose rates is about 0.6 meters thick and expands nearly cylindrically around the vessel cavity. The outer sphere has a somewhat dropshaped contour. Material from this zone is partially radioactive waste as well as restricted material the latter being suitable for disposal on a landfill. The outer contour of this sphere marks the boundary to unrestricted free material which was assigned for remaining in place.

TECHNOLOGY QUALIFICATION

Large efforts were untertaken to select such technologies and equipment which promised trouble free operation during shield dismantling. Among these the excavation equipment was the most important. Different techniques like diamond wire sawing, diamond blade cutting, drilling and water jet cutting were tested on a 1 to 1 scale model of the biological shield. Reinforcement rods, shield cooling tubes and neutron monitor pipes representative for the corresponding components of the reactor shield were embedded into the model. All techniques were carefully tested and analyzed with respect to weak aspects. Finally a commercial hydraulic miniature excavator turned out to be the best tool. This excavator was then equipped with video cameras, spotlights and a remote control system. Different tools like moil and flat chisels, a flame torch, angle grinders and a hydraulic shear could be adapted to the excavator’s arm. The excavator was then intensively tested on the shield model not only to demonstrate its capability to demolish the concrete structure but also to train the operators for the remotely controlled operations.

WORKING AREA PREPARATION

As described above the biological shield had to be demolished with the excavator positioned inside the reactor cavity. The shield expansion into vertical direction is 11 meters which is outside of the direct slewing range of the excavator (about 4 meters). It was therefore necessary to allow the excavator to work at two vertical positions inside the cavity. Two working platforms were installed in the cavity, one at the – 3.7 meter level and the other on – 8.0 meters. In fig. 1 the excavator can be seen in its lower working position. From the upper position the excavator had access to the upper part of the biological shield, while from the lower position it could reach the middle and lower zones. The cavity was isolated from the surrounding building atmosphere by closing all openings (upper and lower cavity cross section and the feed-through shafts of the forced circulation pipework). The upper cross section was isolated with a rotating lid carrying a video system with spotlights on its lower side. The large shaft openings in the side walls were shut with steel plates. At –8.0 meters the lower working platform passed into a conical funnel which at its downstream end was isolated by a gate valve. Below this valve a 200 l-waste drum could be positioned on a separate platform. Concrete debris and metal segments falling down from above were discharged through the funnel into the waste drum. The working platforms were designed as steels grids with large enough openings to allow all debris to pass. All shield material was collected in drums and then sent to subsequent treatment stations. Two HEPA filter units generated a few mbars underpressure inside the cavity, maintaining a definite air flow in the working area. Dust and released activity were deposited in the filter units. The control center with monitors and electronic controls was positioned on the +3.0 m level near to the reactor cavity. A 1.6 Mg slewing crane was used to lower the excavator into the cavity and to bring additional equipment like rotating lid, platforms and tools into position.

DISMANTLEMENT

VAK’s biological shield was demolished in two sequences. First all material with high activity concentration and high dose rate was excavated. This material was part of the inner 0.6 meter layer and had to be classified as radioactive waste. In the following step all material down to about 1.5 meters was removed, 40 % of this material was later on sent to a special landfill. The excavation process was periodically controlled by radiological measurements in order to classify the material with respect to the different radiological classes and in order to make sure that no surplus material was excavated which might have remained in place because its activity concentration was below restriction limits.

Fig. 2 gives an impression of the operating conditions inside the reactor cavity. It shows the excavator on the upper platform shearing off reinforcement rods. The work started in October 2002 and was completed within 9 months. Most of the work was performed in two shifts. About 3 tons of material were stripped per day corresponding to 12 waste drums.

Fig. 2 Excavator I inside the reactor cavity

As described above different tools could be attached to the excavator arm. The most frequently used tools were the chisels. With the moil chisel the concrete in front of a tube or reinforcement layer was first crushed and removed until the embedded metal structure was uncovered. At the beginning the hydraulic shear was then applied to cut the reinforcement rods. Later on with increasing operating experience the rods were smashed with the flat chisel, the concrete behind the rods acting as an anvil. All shield cooling and neutron monitor tubes were exclusively cut with the flame torch. This was sometimes done manually by lowering a cage with a workman into the shield cavity.

WASTE HANDLING

All concrete debris and metal scrap resulting from shield demolition was first filled into 200 l waste drums as described above. These drums were then transferred to a drum scanner where gamma spectrometric measurements were perfomed. Drums with high dose rates (up to 8 mSv/h) obviously contained radioactive waste and the measured data were used to calculate the total activity of the drum contents. In case that the dose rate was low the data were also used to decide whether the material was radioactive or free material. Free material was subsequently sent to a jaw crusher outside the reactor building where metals were separated from mineral material. Only the mineral material was sent to the dump. Radioactive waste material either mineral or metal was filled into so called Konrad Type IV containers. These square shaped steel containers are qualified for disposal in a nuclear repository. The containers have a net volume of approximately 7 m³ and the maximum allowable container weight is 20 Mg. Due to the partially high dose rates it was decided to empty the waste drums by a remotely operated tilting device into the container. In some containers long segments of the neutron monitor tubes were packed together with other metal scrab and then covered by mineral debris from the biological shield. There were still several waste drums filled with contaminated abrasives from water jet cutting of the reactor vessel. These drums which showed a high dose rate were also inserted into the Konrad containers and covered with mineral debris from the shield. The shield material thereby absorbed most of the radiation emitted by the drums.

Fig. 3 shows such a container with embedded neutron monitor tubes. Each tube segment has its own separate index marking its former position in the biological shield. So each single waste component can be followed down the line from its earlier position to the waste container. A loading plan of the container is part of the container documentation.

Shielding of high activated components e. g. the neutron monitor tubes by less activated concrete debris was an important procedure because the national transport and storage regulations require that the dose rate on the container surface must be less than 1 mSv/h. The container wall itself is only a few millimeters thick and is therefore not a sufficient radiation barrier for high dose rate material.

Fig. 3 Waste container with neutron monitor tubes

MASS AND ACTIVITY BALANCE

The total amount of materials and activity removed during demolition of VAK's biological shield is presented in Table II.

Table II Mass and activity balance

	Mass, Mg		Activity	Dose
	radioactive waste	free material	Bq	mSv
Phase 1	147	---	1.7E11	16.8
Phase 2	140	90	2.22E10	9.6
Sum	287	90	1.9E11	26,4

In Phase 1 those data are included which correspond with excavation of the high dose rate zone. 147 Mg of concrete debris and metals had to be filled into waste containers, including 4 Mg of neutron monitor tubes and 8 Mg of lead shielding from these tubes. The total activity of phase 1 material was 1.7E11 Bq. The collective occupational dose accumulated by the personnel was 16.8 mSv.

In phase 2 all low dose rate material was excavated. In sum 230 Mg have been removed, 140 Mg of these have been radioactive waste while 90 Mg could be shipped as restricted free material to a conventional dump. The total activity of the 230 Mg was equal to 2.22E10 Bq and nearly one order of magnitude lower than in the high dose material. In correspondence with the low activity level of phase 2 material the occupational dose of 9.6 mSv was also clear below the phase 1 dose.

287 Mg of radioactive waste resulted from dismantlement of the shield, 275 Mg of these were concrete debris. 35 Konrad Type IV containers were necessary to take up this material. The 90 Mg of landfill material (exclusively concrete debris) were filled into troughs and shipped to a conventional dump.The total activity of 1.9E11 Bq removed from the biological shield was roughly composed of Co-60, Eu-152, H-3 and Fe-55 which contributed with 12,5 %, 31 %, 33 % and 18 % to the overall sum.

The overall occupational dose of 26.4 mSv acquired in about 15,000 working hours is 16 % below the planned value, and the maximum accumulated man dose was 3.5 mSv which is 56 % less than expected.

RÉSUMÉ AND OUTLOOK

VAK is the first German BWR who’s biological shield has been dismantled after 25 years of nuclear operation. The high dose rates required remote shield dismantling. In consequence of careful planning and of application of remote and reliable dismantling techniques the work was not only accomplished in a reasonable period of time but also the occupational dose clearly fell below the expected values. The excavated mass and the produced amount of radioactive waste came close to an absolute minimum because credit was consequently taken on gradual excavation and on legislative release opportunities as well. Especially the availability of a conventional landfill qualified for acceptance of nuclear site material with restricted clearance level helped to meet the targets.

VAK’s biological shield has been excavated down to free clearance levels. Some reinforcements rods remained inside the wall remnants because rod activation expands beyond concrete activation. These rods will be separated later on during conventional demolition of the reactor building.