Lessons learned from the decommissioning of the Belgian Pressurized Water Test Reactor BR3

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ABSTRACT

The BR3 plant was operated with the main objective of testing advanced PWR fuels under irradiation conditions similar to those encountered in large commercial PWR plants. In 1989, it was selected as one of the pilot projects of the European Commission for its R&D programme on Decommissioning of nuclear installations. With the decommissioning of the BR3 reactor, the Belgian Nuclear Research Centre SCK•CEN gained a lot of experiences in the field of decommissioning. This paper describes the main phases carried out in the decommissioning project up till now and will discuss the main lessons to learn.

I. INTRODUCTION

The BR3 plant at Mol in Belgium, was the first PWR plant built outside the USA, at the end of the fifties. It is from the same generation of reactors as the one in Trino Vercelse (Italy) and Zorita (Spain). The reactor had a small net power output (10 MWe) but comprised all the loops and features of a PWR plant of commercial size. In 1964, after 2 cycles, the original Westinghouse internals were exchanged (except for the thermal shield) with different internals for a project called “Vulcain”. The Westinghouse internals were stored in a shielded chamber situated in a corner of the refuelling pool. Although the intention had been to reload the original internals when the Vulcain experiment was completed, this was never done, and the Vulcain internals remained in the reactor until the final shutdown.

The reactor was started in 1962 and shut down in 1987 after 25 years of continuous operation. In 1989, the plant was selected as a pilot decommissioning project by the European Commission within the 3rd framework programme of Research and Technical Development. The table below summarizes the main progress and achievements as:

1987	Reactor shut down
1989	Selected as the European Commission pilot decommissioning project
1991	Full system decontamination of the primary loop
1993-95	Remote dismantling of both sets of highly active reactor internals
1999	Removal of the Reactor Pressure Vessel (RPV) Decontamination facility operational
2000	Cutting out of RPV shell and packaging into 400 litre waste drums
2000-2001	In-situ decontamination of the steam generator
2002	Dismantling of contaminated loops and equipment

	Dismantling of primary main coolant loop
	Transfer of fuel assemblies to dry storage facility
	Dismantling and decontamination of concrete
2009	Final project completion

II. THE DECONTAMINATION OF THE PRIMARY LOOP

The decommissioning project started with a Full System Decontamination of the primary loop and of the associated circuits. The primary loop comprised only one steam generator but, for obvious safety reasons, two primary pumps giving this so-called "1.5 loop system" configuration with two cold legs and one hot leg. This operation allowed the further dismantlement in safer conditions thanks to the dose reduction and thanks to the removal of the contaminated crud so that the spreading of the surface contaminants will be greatly reduced during the cutting operations.
The BR3 team set out the following specifications for the full system chemical decontamination:

- to reach a high mean Decontamination Factor, at least a DF of the order of 10 for the primary loop;
- to minimize the radiation dose associated with the operation;
- to minimize the secondary waste production by concentration of the removed corrosion products and the associated radioactive contamination in a single form, active ion exchange resins, with a volume as low as possible;
- to use the plant as it is, without expensive additional equipments or modifications.

After comparing 3 groups of decontamination processes, the BR3 team selected the CORD process developed by Siemens KWU.

The decontamination of the primary loop proved to be very efficient, with dose rates in the vicinity of the loop reducing by an average factor of 10, enabling operators to work 10 times longer for the same dose uptake or commitment. The decontamination process also resulted in a change of waste category for some of the internal components i.e. ILW to LLW and some HLW to ILW.

III. THE DISMANTLING OF THE THERMAL SHIELD

The thermal shield (see annex 1) is a thick stainless steel cylinder (thickness: 76.2 mm or 3 inches, height: 2.43 m, external diameter: 1.397 m) which surrounded the core and was never unloaded during the whole life of the plant.

Three different cutting techniques were selected for the dismantling of the thermal shield: the plasma arc torch cutting, the electric discharge machining (EDM or spark erosion) and the mechanical cutting using a milling cutter. This allowed comparing three different cutting methods belonging to three types of techniques: a thermal one (the plasma arc torch), an electric one (the EDM) and a mechanical one (the milling cutter). The comparison concerned the amount of generated secondary waste, the cutting duration, the operator's dose uptake and the easiness of the operation. Other cutting techniques, like laser cutting or high pressure abrasive water jet cutting, were also considered but finally not selected because they were still under development and not yet completely mature for the type of cutting, the environment (under water) and the thickness of the material.

The philosophy was to use existing and proven technologies and to adapt them to the environment and to the application. Great care was paid to the dose forecast (ALARA approach), the secondary waste and the operator's safety. Considering the secondary waste production foreseen, it was decided to perform plasma cutting in a closed chamber, located in the reactor refuelling pool, allowing circulating and filtering the water as well as the air situated above the water level (filtration of aerosols, evacuation of the produced hydrogen).

After the design and procurement phases, cold testing of the three techniques was carried out on full-scale mock-ups. These cold tests allowed determining the best cutting parameters, to train the operators and to solve some youth illness of the installations. These cold tests or trials proved to be very efficient in predicting the cutting parameters and in helping to forecast the dose uptake and to optimize the radiation protection. Moreover, the only part which was not fully tested during the cold tests, for practical reasons, was also the one which gave afterwards the most important problems to solve once in the controlled area. This is one of the first important results of this phase of the project: for important operations or activities related to highly radioactive pieces, the use of cold trials on full-scale mock-ups is really necessary and cannot be avoided. It saves finally money and time by allowing solving problems in an easy environment prior to enter the nuclear environment.

The results obtained led to the selection of underwater mechanical cutting as the preferred technique. The main advantages of mechanical cutting can be summarized as:

- well known technique, used in workshops and only requiring adaptation to work under water
- secondary waste (chips or swarf) easily trapped
- low amount of waste if the tool and the kerf are thin
- no emission of smoke, gas or dissolved ions
- overall operation duration comparable to other cutting processes.

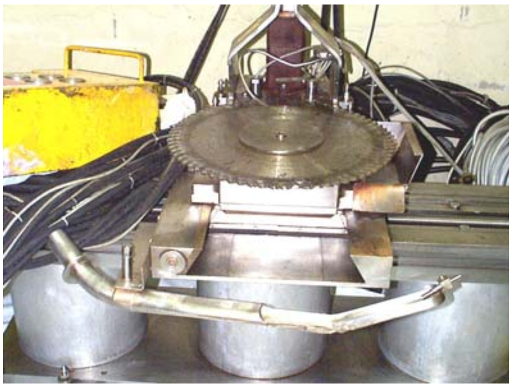
IV. THE DISMANTLING OF THE TWO SETS OF INTERNALS

Thanks to the experience gained with the dismantling of the thermal shield and taking into account the general geometry of the highly radioactive internals (all internal pieces to be cut have a general shape of revolution of elementary surfaces; see also annex 1), it was decided to apply mostly the mechanical cutting technique for their dismantling, where possible. Two main techniques (see photo 1 and 2) were selected: the circular saw and the band saw in association with a so-called turntable. The goal was to cut the highly active internals in segments which have a size fitting closely to the final disposal waste package (400 l waste drum). All cutting operations were carried out underwater in the refuelling pool.

Both techniques were shown to be reliable, usable and efficient. The circular saw produced more volume of secondary waste (metal swarfs) due to a greater kerf width. The required volume of metal (swarfs) to be removed was three times higher than with the band saw. The average overall cutting speed was 1.25 times higher with the band saw. During the project both types of cutting tools were used in a complementary way, but where possible (depending on the height, the shape and the existing access on both sides of the piece), use of the band saw was maximized.
It was originally planned to collect the swarfs during the cut by means of a suction frame surrounding the saw blade. Swarfs were also collected in a funnel with a

collecting basket placed under and inside the work piece. On completion of the horizontal cutting of the Vulcain internals, due to frequent blocking of the suction system, the swarf was no longer collected during the cut, but was pushed into the funnel by a water jet after each cut. The remaining swarfs located on the turntable were then sucked off at the end of each cutting campaign using a straight suction hose. The total calculated weight of swarfs generated for the whole cutting campaign was 133 kg from which 104 kg were collected by the two methods described above. The remaining 29 kg were located at the bottom of the pool and in the reactor pressure vessel and were removed by suction afterwards.

Although the dismantling of the reactor internals was mainly achieved using the cutting techniques described above, several auxiliary techniques were also used to carry out some specific tasks. These tasks included preparing the internals before cutting, disconnecting, to complete a cut begun with a main technique or as a back-up technique. These auxiliary techniques included: hydraulic shears, core drilling, unbolter, reciprocating saws and electric discharge machining (EDM). Although the use of EDM is not recommended as a cutting technique for dismantling thick reactor internals, its flexibility can be advantageous for some "surgical operations". However, any surgical EDM work needs a lot of development and tests to be carried out before implementation as the positioning system of the EDM-head has to be very precise.



Pictures 1 and 2: The two main mechanical cutting techniques used for the dismantling of the reactor internals and the reactor pressure vessel

V. THE DISMANTLING OF THE REACTOR PRESSURE VESSEL

The next phase of the work comprised the dismantling of the Reactor Pressure Vessel (RPV) (see annex 1). The RPV was a 28 tonne carbon steel forged piece clad with stainless steel. The strategy selected for RPV dismantling was:

- Decoupling of the RPV from the primary loop
- Removal of the RPV in one piece from its cavity into the refuelling pool
- Re-instatement of the refuelling pool integrity
- Cutting into rings and segmentation of the RPV into pieces ready for packing.

The figure below, Figure 1, shows the refuelling pool and main systems used during RPV dismantling.

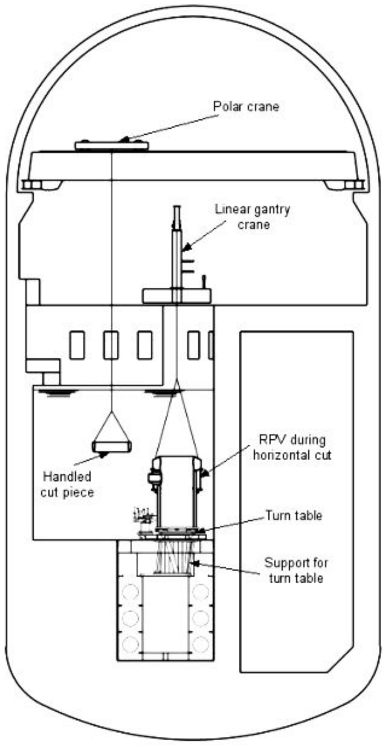


Figure 1. Dismantling of RPV

The cut rings were handled using a set of three automatic clamping devices suspended from the polar crane. These tools were adapted from the industry to be activated remotely. For the manipulation of segments, a specific tool was designed in order to move and place them in the storage racks.

In addition to collecting the metal swarfs that were produced with the cutting techniques, there was also the need to remove and collect the thermal insulation (including particulates of insulation which otherwise reduced visibility in the pool) that surrounded the RPV. Several techniques were employed to collect the problematic insulation, including: the main pool filtration system, an additional external filtration system, collection net, plunger pump and a commercial pool cleaning robot.

VI. THE DISMANTLING OF CONTAMINATED CIRCUITS

Before the BR3 team started with the dismantling of contaminated loops, the team did a lot of research in decontamination techniques. This research led to the development of a chemical decontamination installation and a sandblasting unit. These installations are extensively used in the process to get the most of the contaminated metallic pieces unconditionally cleared.

A first major task was the dismantling of the primary loop and the surrounding loops in the steam generator room. This was necessary to have enough free space around the steam generator and the pressurizer for their later manipulation in the project (decontamination and dismantling). A main challenge was the cutting of the primary loop. As already explained in section II of this paper, the primary loop comprised two cold legs and one hot leg. The cold leg has an outer diameter of 314 mm and a thickness of 31.5 mm while the warm leg has an outer diameter of 412 mm and a thickness of 41 mm. First the BR3-team cut the primary loop in big pieces on site (see photo 3), using a commercial available pip cutter. Next the large pieces of the primary loop were further cut up in smaller pieces with the band saw that was used for the dismantling of the reactor internals and reactor vessel. The pieces had a length of maximum 1 meter so that they could fit in the reactor of the chemical decontamination installation. After decontamination, the BR3-team cleared unconditionally almost the whole circuit.

Photo 3: The cutting of the primary loop (cold leg) with a commercial pipe cutter

After the dismantling works in the steam generator room, the BR3-team went further on with the steady dismantling of the contaminated circuits. This was done following the same philosophy of cutting the loop in large pieces on site and a further cutting up in smaller pieces, mainly in a closed cutting booth. The fact that the loops are contaminated and the dose rate was not high, the operators were able to cut this loops hands on with common and simple techniques like band and reciprocating saws, unbolting and pipe cutters. These mechanical cutting techniques were used for the cutting on site, this to reduce the risk of air contamination while for the cutting up in the ventilated cutting booth common thermal cutting techniques could be used like plasma cutting and grinding. Today, all the loops of the plant are dismantled except the utility services like electricity, ventilation, water circuits and the compressed air circuit. Also the liquid waste circuit with its three liquid waste tanks and the circuit for manipulating the water of the reactor and spent fuel pool with its two recovery tanks are still in service.

With the dismantling of the contaminated loops, the BR3-team faced the huge task of the management of the dismantled materials. Indeed, there are different removal routes (radiological waste, unconditional clearance and conditional clearance) for the materials. There are also different decontamination methods that can be used to put the material in one of the three removal routes. The removal routes and the decontamination techniques have their own and sometimes overlapping criteria which makes the materials management a tough job to do. And the fact that the design of the plant at the end of the fifties was done without the dismantling in mind resulted that in the plant there is always not sufficient space available for an easy and efficient material management. Therefore, the design of the internal material flows has to be looked at very carefully in the preparation phase of a decommissioning project.

VII. THE DISMANTLING AND DECONTAMINATION OF CONCRETE STRUCTURES

In BR3, 28 anti-missile heavy concrete slabs were installed in the reactor pool above the reactor pressure vessel. Characterization studies showed that all the slabs were contaminated and that some were activated. Decontamination of 22 slabs representing 247 t was performed using mainly scabblers, shavers and jack hammer. After treatment, 205 t could be unconditionally free released and sent for recycling in the construction industry and 42 t still slightly activated are kept for further conditioning.

Another main concrete work was the making of different openings in the walls and floors of the reactor building. In a first step, an opening was made in the outer wall of the reactor building and in the operating deck, situated 11 meter high in the reactor to facilitate the removal of the cut pieces from the dismantling of the reactor pressure vessel land the dismantling of the primary loop. In a second step, an opening was made in the operating deck just above the steam generator and the pressurizer. This was necessary for the lifting up of those two big components for their decontamination and their dismantling later on. For these concrete works common cutting techniques were used such as cutting by saw blades and diamond cable cutting. Typical for these techniques is that the cutting tool is cooled with water, forming a not negligible amount of sludges. The managing of this amount of sludges is the main challenge in those types of concrete works. These sludges are sucked up and collected in 200-l drums. The drums will be dried in a drying installation and afterwards characterized. Depending on the results, they will be removed as radiological waste or unconditional cleared.

The last main concrete work carried out until now, is the making of an opening in the spent fuel pool (see photo 4). This fits in the scenario of the future reuse of this pool as a closed cutting booth for big pieces. Specific for this work was that the cuts in the concrete were performed with a dry cutting technique. To avoid too much dust in the working area during the actual cuts, a special suction device was constructed on site and mounted around the kerf. To fact that there was still a lot of dust due to youth-illness problems of the system, shows how important it is to have the necessary attention to the dust collecting system.

Photo 4: This is a view on the diamond cable cutting system used for the making of the opening in the spent fuel pool (the main dust collection system is situated on the other side of the wall and is not visible on the photo).

VIII MATERIALS MANAGEMENT

This section gives some figures on the different quantities treated during the decommissioning project until now. The shown figures reflect the solid materials coming from the dismantling of the installation. Burnable operational waste and liquid waste are not counted in these figures.

The table below gives the masses in kilogram for each removal route (unconditional clearance, conditional clearance and radioactive waste) and the main categories of material (metals, concrete and others).

Type of material material	Unconditional cleared (kg)	Conditional cleared (kg)	Radioactive waste (kg)	Total (kg)
Metals	428779	34183	54360	517322
Concrete	513908	0	30819	544727
Others	22890	0	54940	77830
Total (kg)	965577	34183	140119	1139879

Table 1: The mass of different type of materials removed from sit via the three main removal routs

Because absolute mass figures depend of course of the size of the installation, it is better to use percentages. As almost all the (metal) loops are dismantled in the installation, it is worthwhile to see the percentage of metal that is removed from the site for each removal route. The pie chart below shows the influence of the different used decontamination methods as only 10% of the metals is removed as radioactive waste to the Belgian radioactive waste conditioner.

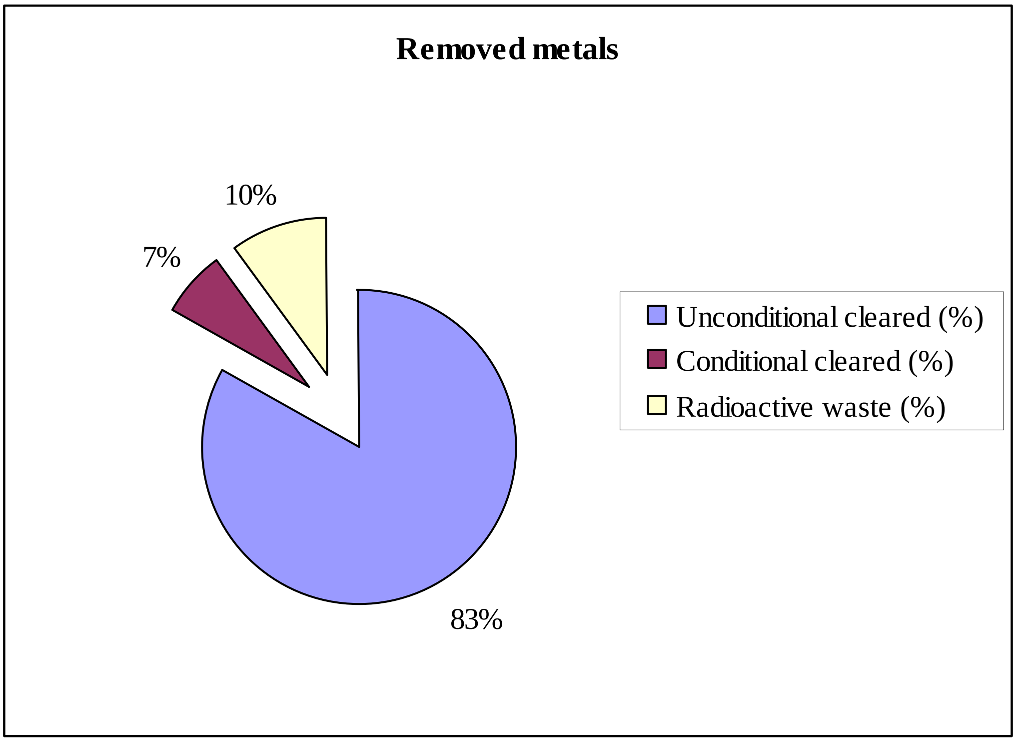


Table 2: Percentage of the removed metals for each removal route

IX. THE LESSONS LEARNED FROM THE DECOMMISSIONING PROJECT

The main experiences gained on the BR3 project showed the following:

- The benefit of full system decontamination in reducing operator doses, and reducing some waste categorization. This operation should be carried out as soon as possible after shut down if existing plant equipment such as the primary pumps, heat exchangers, valves, instrumentation, etc are to be used during decommissioning. This is not only important from aging, maintenance and repair considerations but if the existing knowledge of operators in running that equipment is to be utilized.

- The importance of using full-scale mock-ups to trial the remote dismantling of highly radioactive components. The main advantages being:
  -) Avoidance of having to solve equipment "teething problems" in the controlled area and on contaminated pieces;
  -) optimization of the cutting parameters to produce as little waste as possible and to work as fast as possible for a specific cutting tool and work piece;
  -) testing of the various parts of the dismantling procedure, including the handling of cut components, dismantling equipment and maintenance and tool exchange;
  -) operators to train on the actual dismantling equipment in an environment similar to the actual one, thus leading to shorter operational time and improved understanding of the functioning of the dismantling machines. This also improves the radioprotection of the operators.

- The benefit of using proven industrial cutting techniques for the dismantling of highly radioactive components. The use of proven industrial techniques avoids the R&D or "teething problems" of new technologies and allows better estimating of the amount of waste generated and the actual time to set up and to operate equipment.

- That research and development of new techniques, processes and procedures should be made in research centres and trialled in realistic environments to minimize problems when carrying out the actual dismantling on site.

- The benefit of using under water cutting for the remote dismantling of highly radioactive components. The use of water as radiation shielding is a very effective way of working. The water provides several advantages which are important for the dismantling operation:

    -) a good shielding capacity: e.g. for typical components from LWR reactors, about 2 meters of water thickness are enough for shielding;

    -) full visibility for the operators: as a lot of operations are one-off operations, and as one cannot avoid some surprises in dismantling, direct viewing (i.e. not through television system) is a definitive advantage;

    -) a trapping medium for aerosols and dust produced by various cutting processes. It can also decrease the (toxic and dangerous) gas production from thermal cutting processes with adequate filtering and purification; it can even limit the production of effluents and waste from the operations.

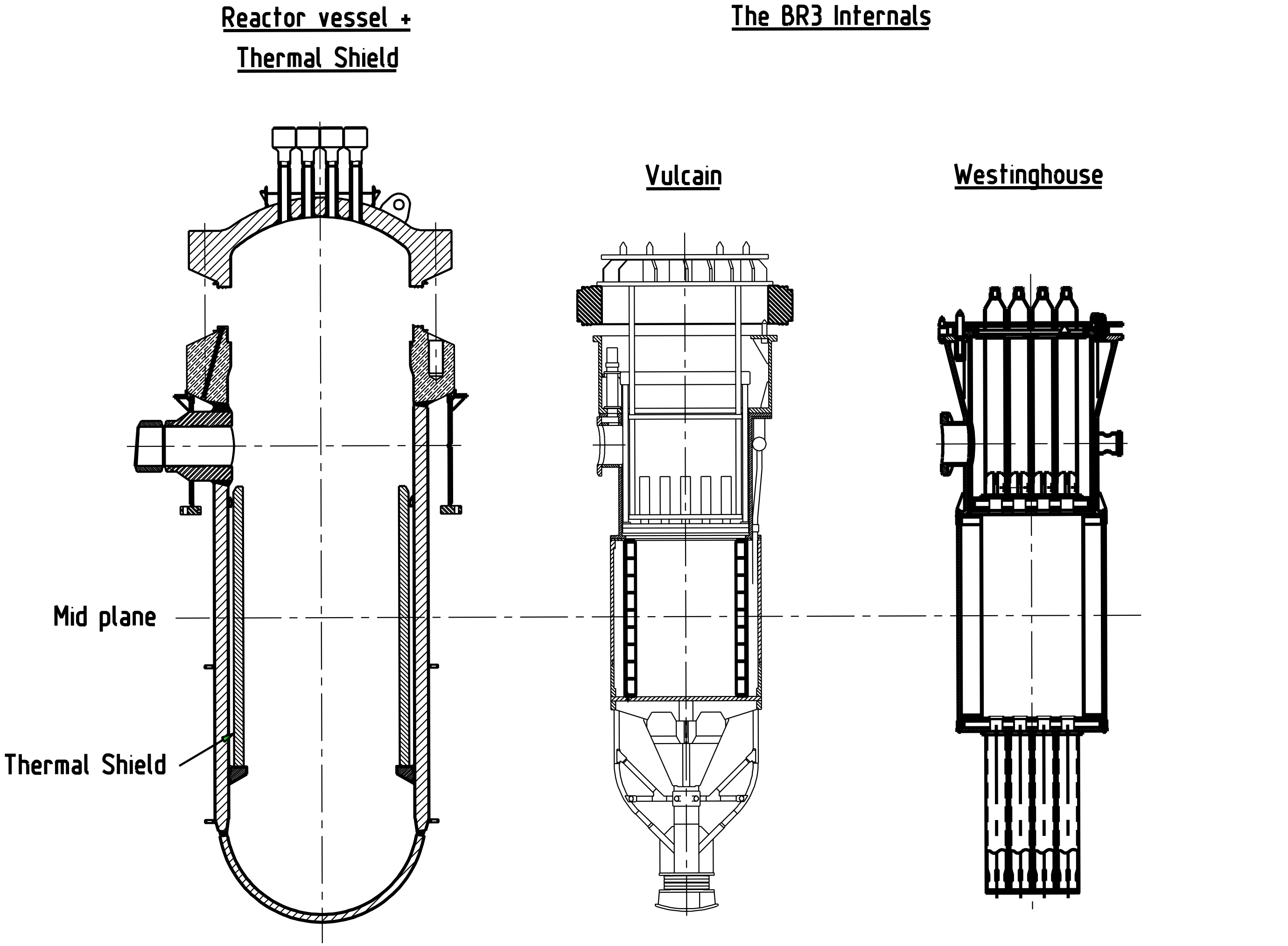
- The underwater operations carried out on different work pieces (and for instance on the two sets of internals, having undergone different decay storage period) have shown that, the different specific activity of the components had no significant influence on the dose uptake of the operator. This can play an important role in the selection of a decommissioning strategy.

- The importance of setting up the waste routes for contaminated materials. The volume of materials to be sorted, handled and consigned is a huge undertaking in decommissioning logistics. The dismantling of a power plant or nuclear installation produces a very large amount of material (waste, contaminated materials, effluent) which has to be managed efficiently to avoid any bottlenecks in the process.

- The benefit of good planning for the installation of handling equipment (e.g. decontamination area, size reduction workshop, sorting area, measurement and characterization areas, truck loading area, etc), so that future dismantling work does not interfere with existing material transfer routes.

- That concrete dismantling or decontamination is a very dirty job which, if not properly managed, (confinement, ventilation and filtration), can spread radioactive contamination. Precautions against contamination spread (whether a wet or dry system is used) are an important factor in concrete dismantling and decontamination.

- Using an easy-to-use ALARA planning tool for optimizing the radioprotection in complex operations. Classical software or calculation tools are often too laborious to use for one-off operations or for comparing different possible scenarios. The application of user friendly 3D ALARA planning tools, which are currently emerging on the market, are proving to be of great benefit.


Reactor vessel +
Thermal Shield
The BR3 Internals
Vulcain
Westinghouse
Mid plane
Thermal Shield
YDM0041

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