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Decommissioning of a small reactor (BR3 reactor, Belgium)

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Abstract. Since 1989, SCK•CEN has been dismantling its PWR reactor BR3 (Belgian Reactor N°3). After gaining a great deal of experience in remote dismantling of highly radioactive components during the actual dismantling of the two sets of internals, the BR3 team completed the cutting of its reactor pressure vessel (RPV). During the feasibility phase of the RPV dismantling, a decision was made to cut it under water in the refuelling pool of the plant, after having removed it from its cavity. The RPV was cut into segments using a milling cutter and a bandsaw machine. These mechanical techniques have shown their ability for this kind of operations. Prior to the segmentation, the thermal insulation situated around the RPV was remotely removed and disposed of. The paper will describe all these operations. The BR3 decommissioning activities also include the dismantling of contaminated loops and equipments. After a careful sorting of the pieces, optimized management routes are selected in order to minimize the final amount of radioactive waste to be disposed of. Some development of different methods of decontamination were carried out: abrasive blasting (or sand blasting), chemical decontamination (Oxidizing-Reducing process using Cerium). The main goal of the decontamination program is to recycle most of the metallic materials either in the nuclear world or in the industrial world by reaching the respective recycling or clearance level. Overall the decommissioning of the BR3 reactor has shown the feasibility of performing such a project in a safe and economical way. Moreover, BR3 has developed methodologies and decontamination processes to economically reduce the amount of radwaste produced.

1. Introduction: The BR3 decommissioning summary

The BR3 reactor was the first pressurized water reactor (PWR) installed and operated in Europe. While its rated power level is low (40 MW(th), 10.5 MW(e) net), it contains all the features of commercial PWR power plants. The reactor was used at the beginning of its lifetime as a training facility for future NPP operators. Later on it was also used as a test bench, in full PWR conditions, for new types of nuclear fuel (e.g. MOX, consumable poison, high burnup,).

The reactor was shut down in 1987 after 25 years of operation.

In 1989, BR3 was selected by the European Union as one of four pilot dismantling projects, included in the third EU five-year research programme on decommissioning of nuclear installations. The project started in 1989 and is ongoing. The first part of the pilot project (1989–1994) involved the decontamination of the primary loop and the dismantling of all the highly radioactive reactor internals.

In 1994, an extension of the contract was signed with the European Union, covering the dismantling of the first set of reactor internal components, which were removed from the reactor 30 years ago. The main goal of this contract was to allow the comparison of an immediate dismantling operation with a deferred operation after a 30-year cooling period.

In 1996, it was decided to carry on with the dismantling of the BR3 reactor pressure vessel (RPV). The first technical acts of this important project were executed at the end of

1997. The dismantling of the RPV was also part of a European contract. In Summer 2000, the last cut on the RPV was carried out and the cut pieces are now in the process of being transferred to the storage facility.

In 1999, the MEDOC decontamination workshop went into industrial service with material clearance as the main objective.

Work is now concentrated on the dismantling of the primary circuit and its large components which will be cut using a promising and quite new cutting technique: High pressure water jet cutting.

Carrying out an important part of this project by itself, the SCK•CEN has gained important experience which allows it to be a specialist in cost evaluation, strategy, study, remote cutting techniques, decontamination techniques, waste management and ALARA evaluations.

2. The dismantling of the reactor pressure vessel

A detailed study for the complete dismantling of the RPV, either in air or under water was carried out. Based on the results of the preceding projects, the mechanical cutting processes were first promoted and analysed.

The studies assessed the overall manpower requirements, scheduling and costs of both operations. For the dismantling of the RPV, the underwater method was finally selected. The RPV was surrounded by an annular Neutron Shield Tank (NST), allowing the vessel to be submerged with only the three penetrations for the primary loop piping needing to be sealed to assure the leak tightness of the pool during the operation.

Further study of the RPV dismantling problems led to the analysis of two different approaches: the in situ dismantling, where the RPV remains in place (under the bottom of the refuelling pool) while it is cut into rings, and the "one-piece removal", where the vessel is removed in one piece into the refuelling pool, and then segmented into pieces ready for packaging.

The advantage of the latter is the accessibility of the RPV and its insulation shroud from the outside, providing the possibility for reuse of the dismantling tools and equipments designed for the internals dismantling. Moreover, this approach greatly simplifies the dismantling of the RPV insulation shroud situated at about 100 mm outside the vessel wall.

2.1. Preliminary operations

These operations (see Figures 1 & 2) were executed with a dry refuelling pool, the RPV still located in its cavity under the bottom of the refuelling pool. Access to the pool floor was possible but had to be reduced as much as possible for radiation protection reasons.

2.1.1. Separation of the RPV from the bottom of the reactor pool

The selected process for cutting at the bottom of the reactor pool was the plasma arc torch handled by an operator. The cutting has to be done quickly in order to limit the dose to the operators. In addition to this operation, different cuts at the bottom of the reactor pool were also needed to give access to the fastening bolts of the RPV support flange, to give access to the hot and cold leg thermal insulation and to allow the installation of the sealing equipment necessary for the future watertightness of the pool.

2.1.2. Removal of the asbestos situated around the primary pipes near the RPV

This operation was carried out by SCK•CEN personnel, as the nuclear hazard was estimated to be far above the asbestos hazard. Nevertheless, to avoid the spread of asbestos fibers, a double confinement was installed in the RPV pool.

2.1.3. Separation of the RPV from the hot and the cold legs

Cutting of the primary pipes at the outside of the bioshield

The main concern for this operation was the cutting of the pipes at the RPV flange level. Because of the very tight space available to perform this operation, access was needed through the primary pipes on the bioshield side. This operation was carried out with a common type of automatic pipe cutter, using two lathe tools diametrically opposed.

Cutting the primary pipes near the RPV

This operation was delicate due to the fact that access was only available from the inside of the piping. With the help of an industrial partner, an automatic milling cutter able to cut the necessary thickness was developed. The challenge was to have a machine fitting into a diameter of 254 mm, able to cut up to 110 mm wall thickness. Finally, it was decided to make a second cut of the primary pipe connections just above the support flange of the RPV in order to gain access to all the RPV fastening bolts. The cutting tool is an automatic milling cutter with a diameter of 30 mm for the first part of the cut, 25 mm for the second, deepest, part.

2.1.4. Separation of the RPV from the NST

A pneumatic wrench was selected for the removal of the 24 bolts fastening the RPV to the Neutron Shield Tank. This operation took about three times longer than foreseen due to the high level of corrosion.

2.1.5. Reinstallation of the water tightness of the NST and the reactor pool

As the RPV and its primary pipes were part of the pool leak tightness system, the openings left after cutting the primary piping, located in a very tight space had to be sealed. The operation was carried out with an industrial partner, who developed a system based on an epoxy-based polymer and a form-shaped sealing system. Cold testing was carried out on a full scale mock up and everything was ready for the installation. During the installation, a major positioning problem arose which will be discussed further on.

Finally the RPV was ready to be lifted. A guiding system had been also installed as the mechanical clearance between the RPV and the sealing devices was less than 10 mm. On August 24, 1999 the pressure vessel (28 ton) was lifted up in one day, using a new gantry crane installed above the RPV pool. The water level in the pool was raised at the same pace as the RPV lifting.

2.1.6. Removal of the insulation shell

The insulation shell is bolted to the RPV through a series of bolts on the four quadrants of the RPV and on the upper side it is bolted to the RPV supporting skirt. It was necessary to remove 60 bolts to free the insulation shell from the RPV. Because of the horizontal position of these bolts they had to be drilled by a remote hydraulic hole cutter. In order to easily reach the different levels at which the bolts were placed, the remote hydraulic hole cutter could move up and down along a beam. Here again, mock-up tests were used.

During the execution of this dismantling task, two problems were encountered. First of all, there was a positioning problem for the cutting tool and second, there was a visibility problem with the pool water. These will be discussed further on in this paper.

2.1.7. Removal of the insulation and the fastening profiles of the insulation shell

The insulation shell was bolted on the RPV by T-shaped fasteners and connection pieces on two levels. Between and on top of these fasteners there is fibreglass thermal insulation, fastened with a metal mesh. The insulation was also held together with metal straps. On the bottom side of the RPV the insulation is held against the RPV with eight straps. These straps are attached on the RPV by bolts through the insulation material.

As the mesh was totally rusted, the removal of the insulation was done using a long handling tool. The liberated insulation fell into a fishing net previously installed on the floor of pool. By remotely closing the fishing net, the insulation was taken out of the water and removed as standard low level waste.

The T-shaped fasteners on the insulation shell were the last items to be removed before the actual cutting up of the vessel could begin. The first approach was to unscrew the bolts of these fasteners. However, due to heavy corrosion of the bolts, these fasteners could easily be ripped off the vessel with a hook. As the fasteners were not very active, their further dismantling was done by hand.

2.2. Dismantling operations of the RPV

The chosen dismantling strategy reuses the existing circular saw (and the existing band saw). New tests were necessary to define new machine cutting parameters because compared to the previous phase of the project (i.e. dismantling of the reactor internals), a different sort of base material (carbon steel instead of stainless steel) and different thickness (112 mm instead of 25 mm) had to be cut.

As the cutting equipment was contaminated during previous phases of the project, the mock-up tests to prepare for the operation had to be carried out in the controlled area.

2.2.1. The horizontal cutting of the RPV using the circular saw

A new clamping device was designed, primarily for use during the first cut with the circular saw. The design of the clamp allowed the upper part of the RPV to be held during and after the cut. The lower part of the RPV was difficult to clamp due to its spherical shape (see Figure 3).

A mock-up of the reactor pressure vessel was made to carry out tests of the cutting technique with the circular saw.

The first series of mock-up tests brought some problems to light:

- the mock-up vibrated a lot;
- the selected type of sawblade seemed not ideal for the purpose.

The results of this first series of tests led to:

- the construction of a stiffer clamping system;
- the detailed analysis of the requirements of the cut, concerning the saw blade design;
- the organization of an extended second series of tests.

The second series of tests had as objectives:

- to validate the new clamping system device (see Figure 4);
- to try and optimize the cutting sequences and their associated parameters.

Both objectives were finally reached and the actual work could start The estimated duration of the operation was 107 shifts on the basis of a mean feed speed of 15 mm/min. In fact the actual duration of the operation was 65 shifts, a reduction of 42 shifts, mainly because of much better performance of the sawblades (feed speed up to 80 mm/min and a longer life span). Similarly, the actual integrated dose received was only 3.652 man-mSv in place of the 9.784 man-mSv estimated. Figure 5 shows the refuelling pool during horizontal cutting.

2.2.2. The vertical cutting of the RPV using the band saw machine

Vertical cuts through the nominal thickness of the RPV (112 mm)

During mock-up tests, a few cuts were carried out in the SS clad carbon-steel wall of the RPV mock-up without any problem, using a feed speed of about 20 mm/min. This immediate success was thanks to a similar job that the BR3 team had already carried out during the previous phase of the project (i.e. the dismantling of the instrumentation collar). There were no major problems with the cutting operation. However, the cutting speed used was much lower than during the mock-up tests: 9,5 mm/min. During the segmentation of the two first rings, many sawblades were used. To avoid this high consumption of sawblades for the other rings (included the additional time required for the blade exchange), the cutting speed was reduced.

Vertical cuts directly through the RPV flange followed by a horizontal cut through vessel-insulation-shroud (all 3 in the same time)

The cuts through the flange (thickness 355 mm) were successful at 7 mm/min. Special attention had to be paid when cutting near the weld situated below the flange where there is a risk of jamming the blade. The major difficulty when cutting the RPV flange was due to a 2 cm thick supporting shroud under the flange. This meant that when cutting the upper part of the RPV, the band saw had to simultaneously cut the flange followed by the vessel + insulation + shroud. The influence of the insulation on the cutting performances was unknown and had to be tested. Finally, the tests and the actual cuts were carried out without any problem. Figure 6 shows one piece of the reactor pressure vessel. Since this piece had only a low level of activity, it was put in the drum "hands-on". The pieces closer to the core, much more activated, were manipulated remotely under water.

3. Encountered problems and solutions

During the dismantling phase of the RPV, the team encountered two major problems: some "non conformities" or discrepancies with the "as built" drawings and severe turbidity problems with the cutting pool.

3.1. Problems with the "non conformities" of as built drawings

As already explained earlier in the text, one had to retain the watertightness of the reactor pool. This would be done with three special designed sealing devices. Early on in the dismantling process one had to stop the operation because it was impossible to properly position the sealing devices due to discrepancies between the "as built" drawings and the actual equipment. Figure 7 illustrates the problem: a metallic lath (which was thicker than indicated) made it impossible to push the sealing device correctly against the NST inside wall. Therefore, the design of the sealing devices had to be revised, and the sealing devices themselves had to be adapted. The positioning of these devices was finally carried out in June 1999 instead of March 1999.

Discrepancies are a common problem in the dismantling of old nuclear facilities. Another problem in the same category is the one encountered with the insulation shell removal. At the outset, it became almost impossible to locate the screw heads due to a high level of corrosion on the shroud surface (see Figure 8). Therefore it was impossible to locate these bolts to cut them with a hole cutter machine. It was then decided to cut the entire circumference of the core shroud at the corresponding level of the bolts. This method required 10 times more holes to be cut than planned.

3.2. The turbidity problem of the pool

When the insulation shell (a protective metal sheet for the thermal insulation situated around the RPV – see Figure 8) was removed a major problem occurred: significant water turbidity appeared. This was due to the thermal insulation which became breakable into something looking like dust but also to rust. Sometimes, the visibility was so bad that the operation had to be stopped. Additional filtration and purification facilities were installed to solve this problem. The same problem appeared again when the cut with the bandsaw for the removal of the vessel flange was carried out. Remaining insulation, situated under the vessel flange again entered the pool water and caused a new turbidity problem. Figure 9 shows the turntable coming out of the pool water.

To clean and purify water, it is necessary to first remove the particles in suspension and then the dissolved ions in order to lower the conductivity. Filtration tests were performed at the pilot scale, which showed that it was necessary to use at least a 1.2 μm filter.

The existing refuelling pool water purification system comprises a filter unit with a capacity of about 20 m^3/h and a 210 l ion-exchange column with a capacity of 2.5 m^3/h. The filters used are 10" wound 1 μm polypropylene filter cartridges. The ion exchanger is a homogenous mixture of strongly acidic cation resin and a strongly basic anion resin.

This system was insufficient to deal with the heavy pollution observed; moreover it appeared that the ion exchange column was saturated. Therefore, several actions were undertaken:

- installation of an additional mobile filtration unit with a capacity of 20 m^3/h pumping directly in the pool
- replacement of the saturated resins
- installation of two mobile ion exchange columns at the outlet of the mobile filtration unit with a capacity of 2 to 3 m^3/h.

After these items were completed, the visibility could be kept under control except during short periods of peak pollution corresponding to release or resuspension of rust or fibres. To maintain a high water quality, it was necessary to regularly replace the saturated filters or resins. During the reactor pressure vessel cutting process, the production of secondary waste amounted to about 2.9 m^3 of burnable cartridges and 0.7 m^3 of burnable ion exchange resins.

4. RPV waste

The Belgian National RadWaste Authority (ONDRAF/NIRAS) has the responsibility of establishing the different acceptance criteria for waste types and waste packages. For the solid waste (big pieces), there are three major groups of waste, distinguished by the contact dose rate. These are Low-Level solid waste (LLW) with a contact dose rate < 2 mSv/h, Medium-Level solid waste (MLW) with a contact dose rate between 2 mSv/h and 0.2 Sv/h and High-Level solid waste (HLW) with a contact dose rate > 0.2 Sv/h.

There are only two different types of waste packages, namely the standard 400 l drum and the standard 200 l drum. The 400 l drum is used for large pieces. At the waste facility these drums will be filled with concrete. The 200 l drum is used for small pieces and is intended for supercompaction.

The reactor pressure vessel itself led to the production of a high volume of waste, more particularly high- and medium-level waste. For radiation protection reasons, this waste had to be manipulated under water. In total, nine shipments were made to the Belgian waste conditioner and intermediate storage facility representing a volume of 3.6 m^3 of high-level waste (including highly activated swarfs). The medium-level waste was manipulated with the same rack system and represented a volume of 4.8 m^3. Low-level waste, primarily the vessel flange and the bottom ring led to a volume of 6.8 m^3.

5. Management routes for contaminated metals

5.1. Disposal routes

Dismantling of a nuclear reactor produces large quantities of materials and associated gaseous, liquid and solid effluents. Not only primary materials are produced i.e. the items dismantled but also secondary materials e.g. tools, equipments, new hardware for dismantling and decontamination and secondary effluents from the dismantling operations.

The major solid materials coming from the dismantling operations are:

- Burnable wastes
- Low to High level massive metallic wastes
- Low to High level super-compressible metallic wastes
- Massive concrete wastes
- Concrete and bricks of super-compressible rubble

- Sludge
- Various light non metallic super-compressible materials
- Special waste

Three main material categories can be distinguished:

(a) Material which can be considered as conventional and treated as such, e.g. disposed of as industrial waste or recycled in the industry: emergency power supply, tertiary loop, components outside the controlled area.
(b) Material which has to be disposed of as radioactive waste, e.g. activated materials or heavily contaminated material which cannot be technically or economically decontaminated or cannot be recycled or re-used: reactor pressure vessel and its internals, highly activated concrete, contaminated materials, etc.
(c) Material which has to be considered as radioactive material, but as an alternative to its disposal as radioactive waste can be cleared unconditionally after decontamination, cleared after melting or recycled in the nuclear industry: contaminated piping, reservoirs, pumps, structural equipments, contaminated concrete, etc.

5.2. Work organization

The dismantling of a nuclear facility is a complex task. Therefore the dismantling operations are divided in hundreds of different tasks or work packages. For each task, a working procedure is established. This procedure gives the details of the work to be done and makes an analysis of the safety aspects (conventional and radiological). The work is only started after approval from the Health Physics group attached to the facility.

The main steps followed for a typical dismantling work package, such as the cutting of a contaminated loop, are:

- On site ***dismantling*** in large pieces
- ***Cutting*** in small pieces in a ventilated workshop
- ***Sorting***
- ***Identification***
- ***Temporary storage***
- ***Treatment*** (washing, chemical decontamination)
- ***Characterization***
- ***Disposal.***

In this process, the crucial point is the ***sorting***. It has to be carried out as soon as possible after dismantling (cutting) in order to guarantee the traceability i.e. where does it come from, what is its history? The sorting of the material must be well prepared in advance to accelerate the operation. The operator must know the destination of the material. The decision depends on the contamination level, the geometry of the pieces, the materials composition, the nature of the contamination, etc.

The sorting of the dismantled material leads to the creation of "batches", groups of materials that will follow the same disposal routes. Every batch carries a unique identification label. The content of a batch, its status and its location must be known at each moment.

All relevant information is collected:

- A unique identification number is written on a label fixed on the batch; this label gives the content of the batch, its weight and the disposal route selected.
- The actual status is reported in the database
  - In buffer storage before treatment
  - In the characterization process
  - Disposal route selected
  - Cleared, disposed of as radwaste, or in storage
- Finally, a document is created with all the necessary approvals. It functions in the selected disposal route as a clearance document, a request for treatment as radioactive waste or an authorization to send to a melting facility.

5.3. Treatment of radioactive metals by melting

Nowadays, "nuclear" melting facilities are in operation in several countries for the treatment of low-level metallic wastes. To be cost effective, these installations must have a sufficient throughput. At the moment, Belgium does not have an available facility so contracts were negotiated with facilities abroad.

5.3.1. Melting for recycling in the nuclear world

Low level radioactive materials may be recycled in the nuclear world. The melted materials are used for the fabrication of shield blocks or for the fabrication of radioactive waste containers. SCK•CEN has an agreement with GTS-Duratek in the USA; the recycled materials are used as shielding for the DOE facilities. The materials meet stringent composition and radiochemical criteria. The secondary wastes are conditioned and disposed of by Duratek.

Future shipments of materials in this category are being considered such as:

- Materials slightly activated: metal shielding, pool liners, fuel storage racks.
- Materials of complex geometry not possible to decontaminate economically: heat exchangers, pumps, complex structural materials, small pipes.

5.3.2. Melting for clearance

Some dismantled materials are either very low contaminated, very difficult to measure or not homogeneously contaminated. For these materials, it can be advantageous to send them to a nuclear foundry. Melting offers several advantages:

- It decontaminates the metals by volatilization of some nuclides (e.g. ^{137}Cs) or by transfer to the slag (e.g. heavy nuclides such as alpha emitters).
- It allows an accurate determination of the radionuclides content thanks to the homogeneity of the metal melt.
- The amount of secondary waste (dust, slag) is rather low.

Future shipments in this category are being considered, including:

- Materials not able to meet the criteria for direct clearance after decontamination.
- Heterogeneous materials containing hot spots and/or activity difficult to measure.

The materials will be separated by type (carbon steel, stainless steel, copper, aluminum); lead and galvanized steel are not accepted in this foundry. The paint must be removed from the pieces either by sand blasting in our facility or by sand blasting in the Studsvik facility. The presence of organic matter and encapsulated water must also be avoided.

5.4. Clearance of metallic materials

The steady increase of conditioning and disposal costs as well as environmental concerns and public perception are pushing the nuclear sector to decrease the amount of radioactive waste generated and hence produces a strong incentive for the development of thorough decontamination processes and procedures for the clearance of obsolete radioactive materials and their reuse in the industrial sector or their disposal as industrial waste.

The clearance of radioactive materials requires a combination of factors to be successful:

- Procedures and well-defined clearance criteria: a consensus is not yet achieved on international level and generally a case by case management is still applied. IAEA, EU, OECD are progressively converging towards some harmonization. The council Directive 96/29 Euratom, that had to be implemented in national legislation by May 2000, does not prescribe the application of clearance levels by competent authorities It is up to the Competent Authorities to establish clearance levels below which the disposal, recycling or reuse of materials is released from the requirements of the Directive. In our case, the Health Physics department under supervision of the Competent Authority establishes procedures. This procedure is still a "case by case" practice and is applied currently for the clearance of materials from the BR3 dismantling.
- A strict accounting of the dismantled materials comprising origin of the materials, treatment performed and characterization results.
- The traceability of the materials must be guaranteed at each step: this can only be achieved with a strong Quality Assurance program, presently being implemented.

The characterization of materials to be cleared is still a difficult topic. Materials, which are candidate for clearance without melting, can be subdivided into 3 categories:

- Materials of simple geometry for which a 100% surface measurement is possible using hand held β monitors. For these materials, surface specific clearance values are established and the procedures are well known. The values used are 0.4 Bq/cm^2 for $\beta\gamma$ emitters and 0.04 Bq/cm^2 for α emitters.
- Homogeneous materials such as concrete rubble for which only volume or mass measurement is possible. For these materials, international mass specific guidelines are generally followed and measurement procedures are available (e.g. γ spectrometry of the whole amount in a 200 l drum or statistical sampling after homogenization). There are for the moment no fixed legal values for the clearance of such bulk materials; the health physics consider this still on a case by case basis. Their decision depends not only on the measured level but also on the origin of the material, its history and its final destination (e.g. recycling as scrap materials or disposal as industrial waste).
- Materials of complex geometry and/or heterogeneous (pipes internally contaminated, pumps, valves.): the question is how to prove that the activity level is lower than the current clearance guidelines? A procedure, based on a double measurement method has been worked out.

We use:

- Hand held ß monitors for direct surface measurements
- For volumetric measurements
  - Spectroscopy HPGe detectors: Q2-220 l waste barrels.
  - Versatile spectrometry with HPGe detectors: Isocs system.
  - Gross gamma counting with scintillation detectors: the ESM CCM monitor.

The procedures followed are:

- Hand held monitors for easy to measure materials; 100% of the surface measured twice at a max 3 months interval for materials submitted to a decontamination treatment (sweeping effect).
- For homogeneous materials, we actually use the Q2 spectrometer for measurements of 200 l drums.
- For heterogeneous materials, we have two possibilities:
  - The materials are sent to a nuclear foundry, which allows a further decontamination and a reliable measurement thanks to the homogenization.
  - We combine two measurements techniques:
    (i) A gross gamma counting with scintillation detectors for measurements of individual pieces or of small batches (1/10 of a 200-l drum).
    (ii) A Q2 spectrometer for the determination of the specific activity per individual gamma nuclide.

The Q2 spectrometer is well known whereas the ESM CCM gross gamma counter for the small batches as well as the Isocs system were recently developed and the results obtained were compared.

6. Decontamination techniques

For metals, we use mainly:

- Manual washing or cleaning in an ultrasonic rinsing bath: mainly for pieces only slightly contaminated by deposition of contamination on external surfaces (demineralized water piping, structural pieces, instrumentation boxes...).
- Wet abrasive decontamination: mainly used for rusted or painted pieces of simple geometry in which the contamination is fixed in the oxide layer or in the paint (structural equipment, beams...). An installation called ZOE is used for the treatment of pieces up to 3 t and 3 m long maximum.
- Hard chemical decontamination with the MEDOC Cerium process: mainly used for stainless steel pieces heavily contaminated up to 20,000 Bq/cm^2 ^{60}Co (primary loop, tanks,...). The Medoc installation has a capacity of about 0.5 to 1 t of metals per batch which can be treated in one day.

Up to now, about 50 tons of metals have been treated in these different decontamination workshops. About 10 to 20% were not directly cleared; they are then sent to a nuclear melting facility for further decontamination and clearance or for recycling in the nuclear industry; the choice between the melting facilities is a function of the residual contamination present.

7. Conclusions

The BR3 Pilot Dismantling Project has allowed various dismantling techniques to be tested under fully representative conditions. The dismantling of the highly radioactive internals allowed the comparison of different cutting techniques and demonstrated the feasibility of such operations. Likewise, a reactor pressure vessel was totally removed from the plant containment after safe segmentation.

The comparison of the techniques led to a preference for mechanical segmentation techniques, which are well known in the industry and require only adaptation for working under water and in a nuclear environment.

The experience gained with a pilot reactor like BR3 provides SCK CEN with the knowledge of detailed costs, doses, waste and risks for the dismantling of a nuclear reactor. The SCK•CEN is now able to evaluate the cost and duration of such an operation, to give advice and to support dismantling operations, and to advise on design and operational guidance in order to facilitate future decommissioning of nuclear installations.

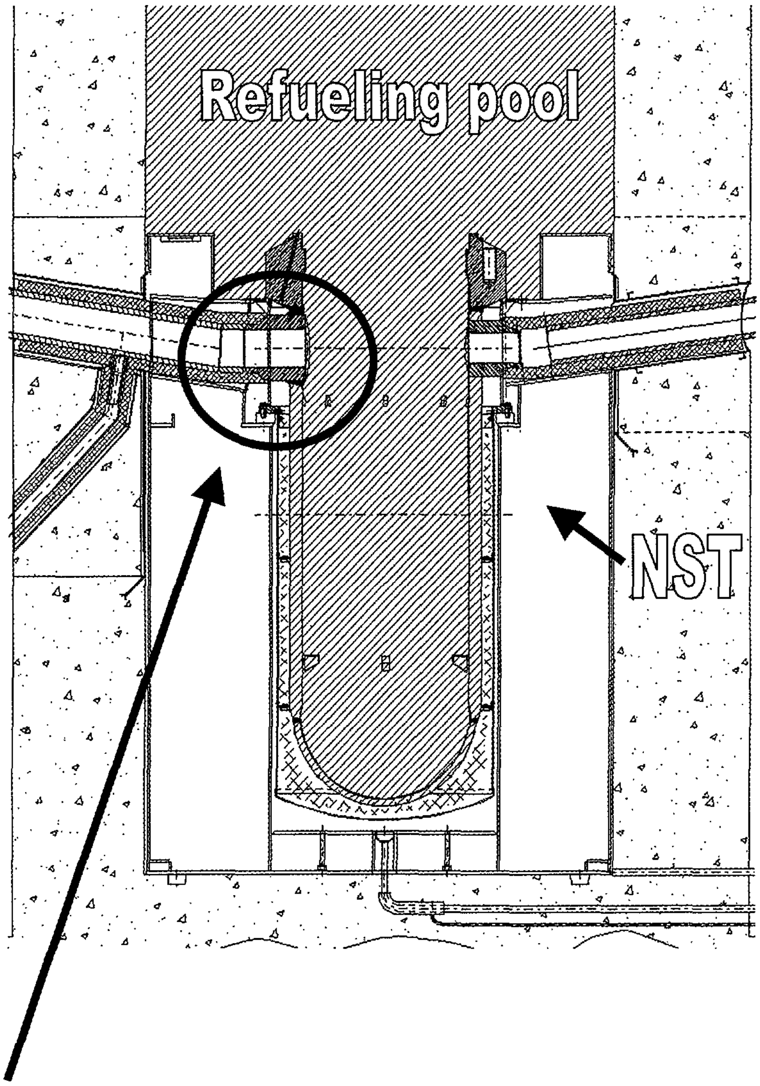
The management of dismantling materials, with the objective of minimization of the amount of radioactive waste by applying decontamination and clearance or recycling, is a complex task due to the high variety of materials, the high variety of contamination levels and the low level measurement issues.

We have demonstrated that this is technically feasible and that it is cost effective since the overall cost of the decontamination-recycling-reuse route is still lower than the disposal and replacement route. Moreover, it saves natural resources and decreases the radioactive waste volumes.

This choice implies the setup of a strong Quality Assurance program to guarantee the traceability and to push the industry to develop cost-effective decontamination and measurements techniques.

Harmonization of the different regulations and the adoption of "reasonable" clearance levels are major efforts that must still be carried out.

Even though BR3 was a small power plant, the results and lessons learned can be used to derive data for other nuclear installation dismantling: the radiological, waste and technical problems are similar.



Look to figure 2 for close-up

Figure 1. Due to the presence of the NST, there is no "easy" access to the thermal insulation of the RPV.

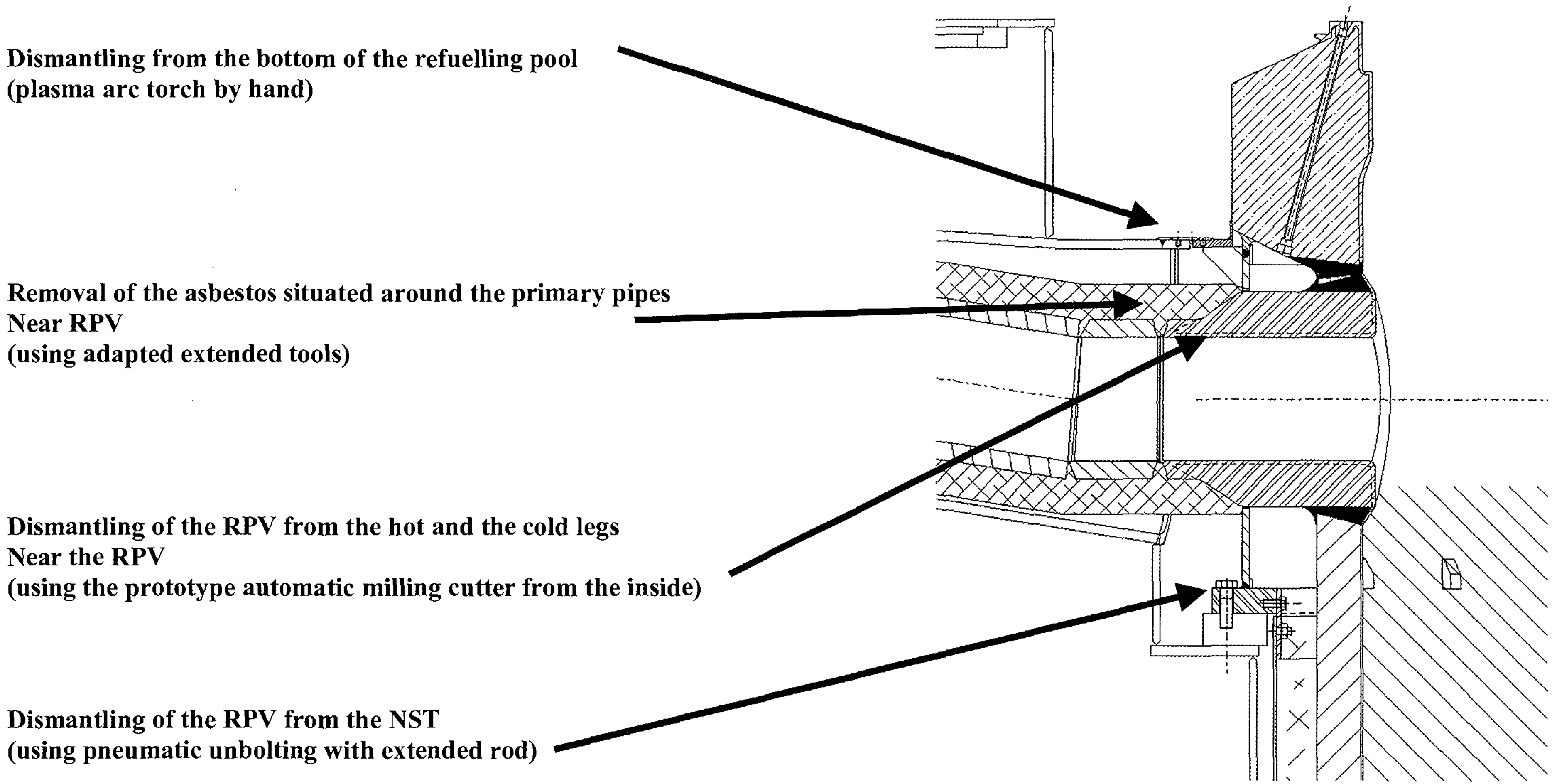


Figure 2. The dismantling steps for the reactor pressure vessel.

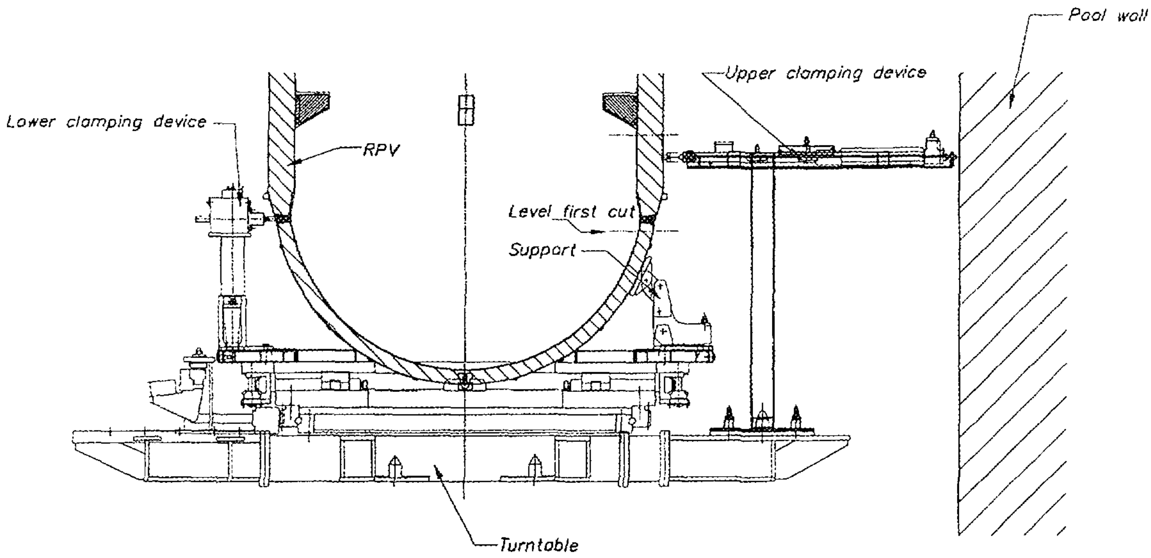


Figure 3. The spherical shape of the RPV bottom required additional clamping devices.

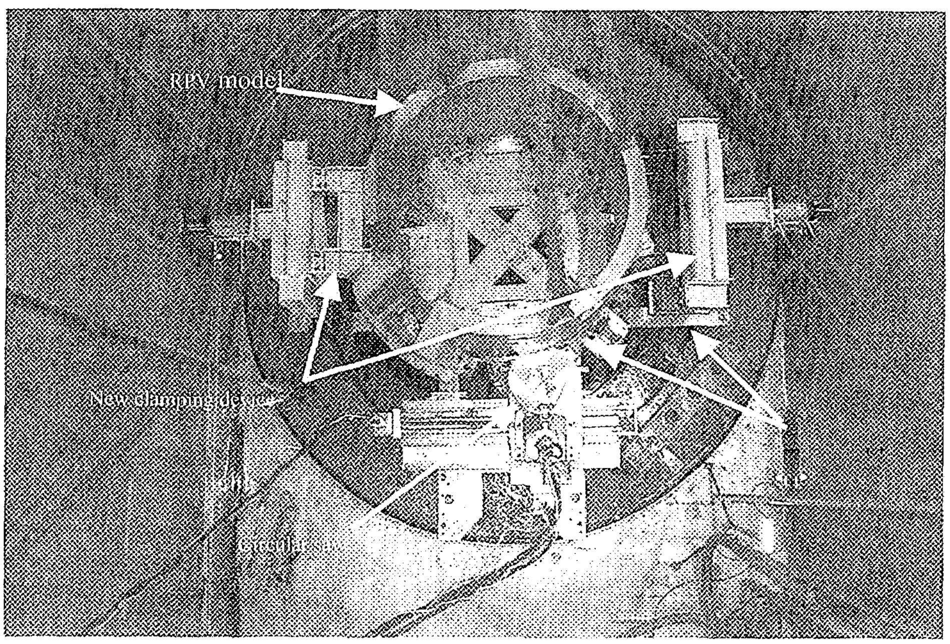
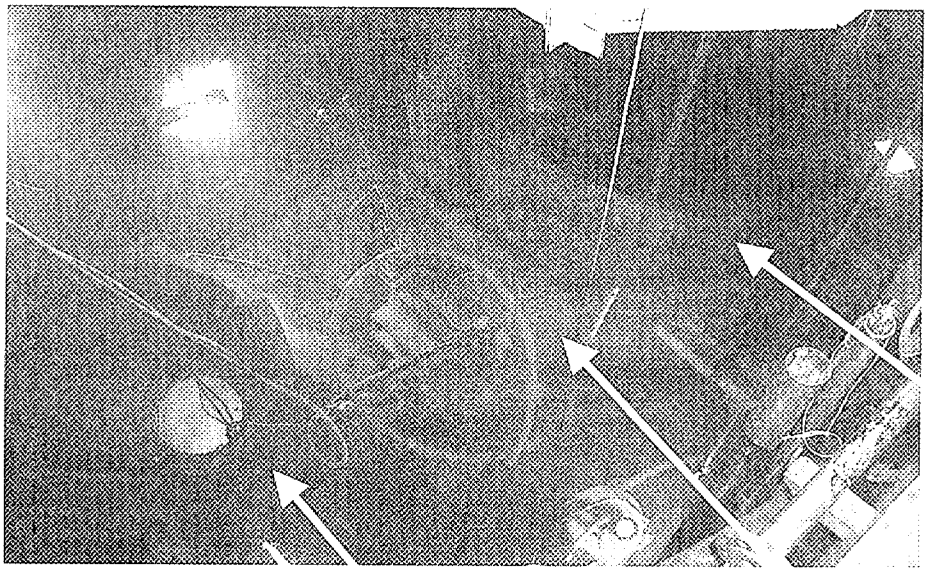


Figure 4. New clamping devices were built.



RPV

Cut ring

Milling cutter

Figure 5. Dismantling activities during the horizontal cutting.

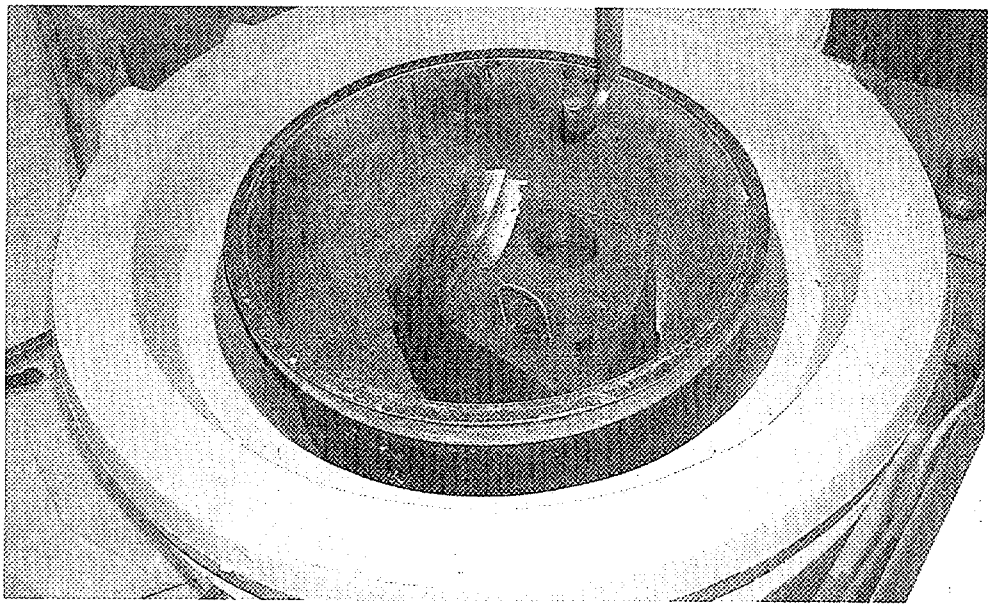


Figure 6. One piece of the RPV flange put into a 400 l drum for disposal as low level waste.

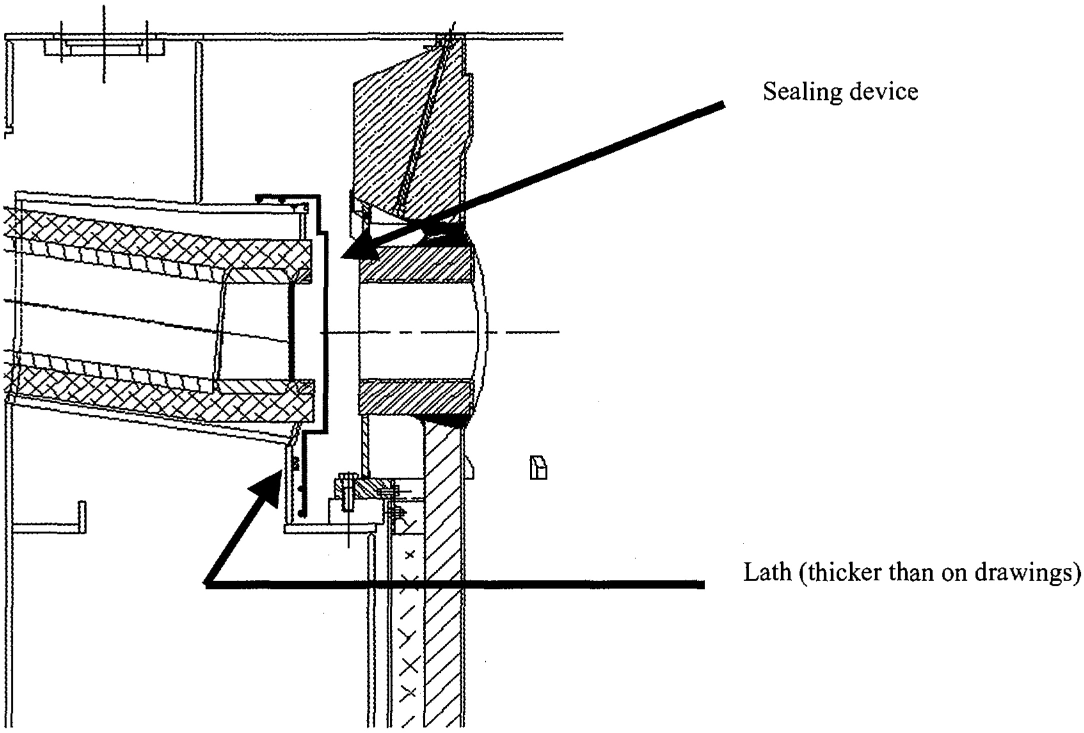


Figure 7. First major problem: the lath (thicker than foreseen on drawings) makes the positioning of the sealing device impossible.

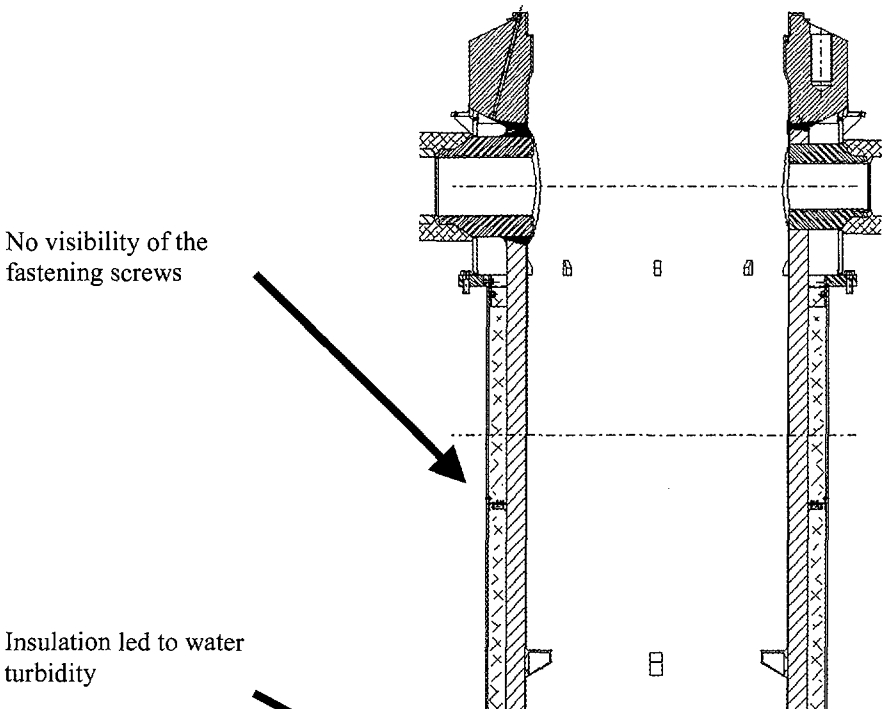


Figure 8. Second major problem: no visibility of the screw implied additional operation and the insulation led to pool turbidity.

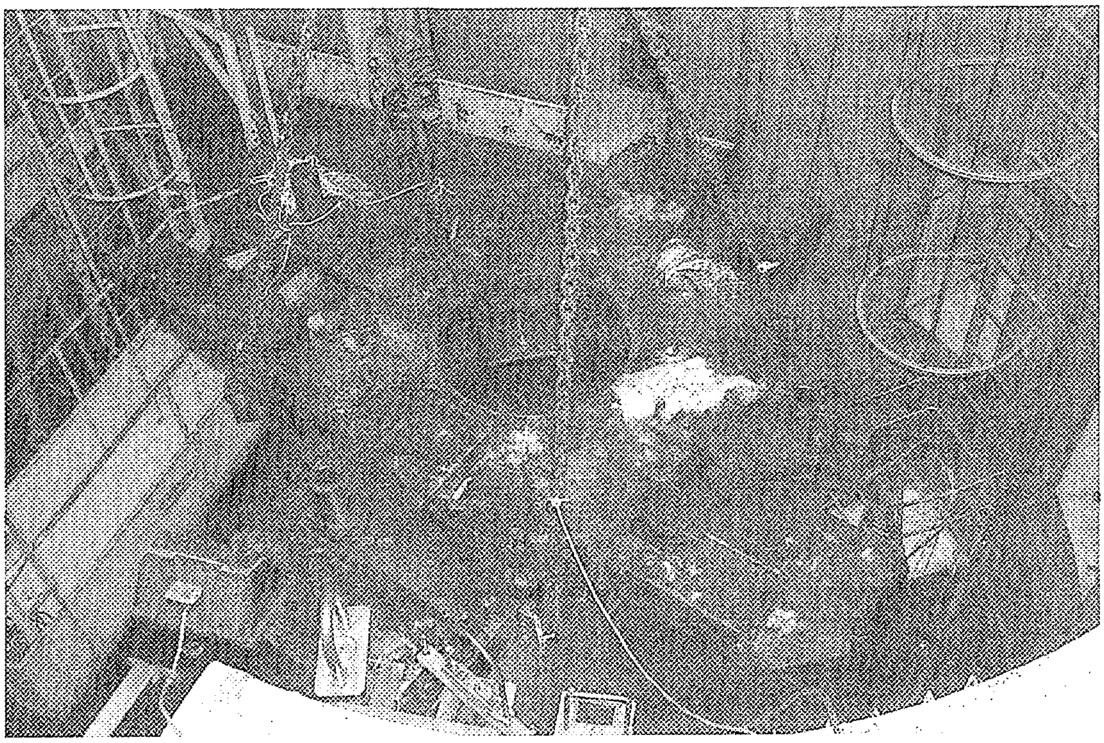


Figure 9. View of the turntable removed from the pool after the turbidity problem.

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