DD-38 Rev.1 (ENG)

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Decommissioning of DR 2

Final report

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Summary

This report describes the work of dismantling and demolishing reactor DR 2, the waste volumes generated, the health physical conditions and the clearance procedures used for removed elements and waste. Since the ultimate goal for the decommissioning project was not clearance of the building, but downgrading the radiological classification of the building with a view to converting it to further nuclear use, this report documents how the lower classification was achieved and the known occurrence of remaining activity. The report emphasises some of the deliberations made and describes the lessons learned through this decommissioning project. The report also intends to contribute towards the technical basis and experience basis for further decommissioning of the nuclear facilities in Denmark.

The present document is a translation of the original report in Danish that was approved by the nuclear licensing authorities on April 30, 2009. A few clarifying changes of the text have been introduced relative to the direct translation.

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Preface

DR 2 is the second of three research reactors on the Risoe site that has been decommissioned. The dismantling work started in the spring of 2006 following a two-year planning period.

The reactor was in use from 1959 to 1975. Consequently, the decay period has been over 30 years; however, the reactor still contains components with considerable radioactivity. The actual decommissioning of the reactor block started in May 2006 and was completed in mid-2008.

Dismantling of the most active parts of the reactor, such as the experiment tubes, fuel grid plate and thermal column, was carried out by DD's own staff. The typical participants for such operations would be two technicians, one health physics technician, one technical assistant and, in some cases, one engineer. The demolition of the biological shield and the necessary parts of the floor under the reactor was carried out by a Danish demolition contractor under continuous monitoring by DD staff. Typically, the demolition contractor had two to four people working on the assignment at a time. The cooperation with the external contractor went extremely well; in this connection it was probably no disadvantage that following a public procurement procedure, the successful tenderer was the same contractor who was in charge of demolishing the concrete on DR 1.

This report will contribute towards the technical basis and experience basis for the further decommissioning of the nuclear facilities in Denmark.

1 Introduction

Danish Decommissioning (DD) is charged with decommissioning the nuclear facilities at RISOE National Laboratory. Research reactors DR 1 and DR 2 are the first facilities out of six to be decommissioned; hence they represent a special challenge and, not least, a risk of unforeseen issues that may necessitate the use of special equipment and special methods. The reactors and laboratories at RISOE are the only nuclear facilities in Denmark; consequently, decommissioning of these facilities will be the first and only such assignment in the country. The decommissioning of DR 2 is thus very significant in terms of DD's future projects, particularly the DR 3 project.

Since the reactor has been closed for more than 25 years, it is the one reactor - after DR 1 – that is expected to give the least problems. That is why it was initially decided that these two reactors would serve as learning cases prior to the decommissioning of the remaining nuclear facilities, in particular DR 3 (10 MW, closed in 2000). The decommissioning of all nuclear facilities at RISOE is expected to run until 2018.

The overall purpose of decommissioning the nuclear facilities at RISOE is to obtain a green field, meaning that the area and any remaining buildings can be used for other purposes without any restrictions (in regard to radioactivity). A more detailed description of the reactors and the nuclear facilities at RISOE is given in [4].

Whenever possible, DD carries out decommissioning by using its own staff and expertise. In some cases, the work calls for special tools and expertise that will be supplied by external contractors and specialists. Dismantling work at DR 2 has largely been carried out using tools and expertise already available at DD. However, a number of special-purpose tools have been acquired for specific assignments.

The decommissioning of DR 2 was planned for the period 2005–2008. The project description was approved by the nuclear supervisory authorities in December 2005 and the budget (the Parliamentary bill) was approved by the Finance Committee in May 2006. Decommissioning commenced shortly after and was finalised with the assignment of a lower classification of the containment building in mid-2008. This final report, which describes the process, was prepared immediately following this finalisation.

This report describes the methods and processes chosen for decommissioning of the reactor. The report includes such elements as descriptions of the decommissioning activities, the radiological status, the decommissioning waste generated, the lessons learned, as well as the clearance procedures and processing of assigning a lower classification.

2 Description of facilities and surroundings

DR 2 was a light-water cooled and moderated heterogonous research reactor of the open tank type with a thermal output of 5 MW. Highly enriched uranium was used in the fuel elements.

DR 2 first reached criticality in late December 1958 and was finally closed down in 1975, when reactor DR 3 had enough capacity for the scientific tasks and the production of radio-isotopes and other radiation assignments. The Nuclear Energy Commission (AEK) purchased the reactor from Foster Wheeler Corp. in New York, which supplied the reactor components, drawings and specifications prior to installation. The reactor was installed by Danish contractors.

The location of DR 2 on the Risoe site is shown in figure 1. A detailed description of the Risoe site and its surroundings is given in the safety documentation for Danish Decommissioning [4].

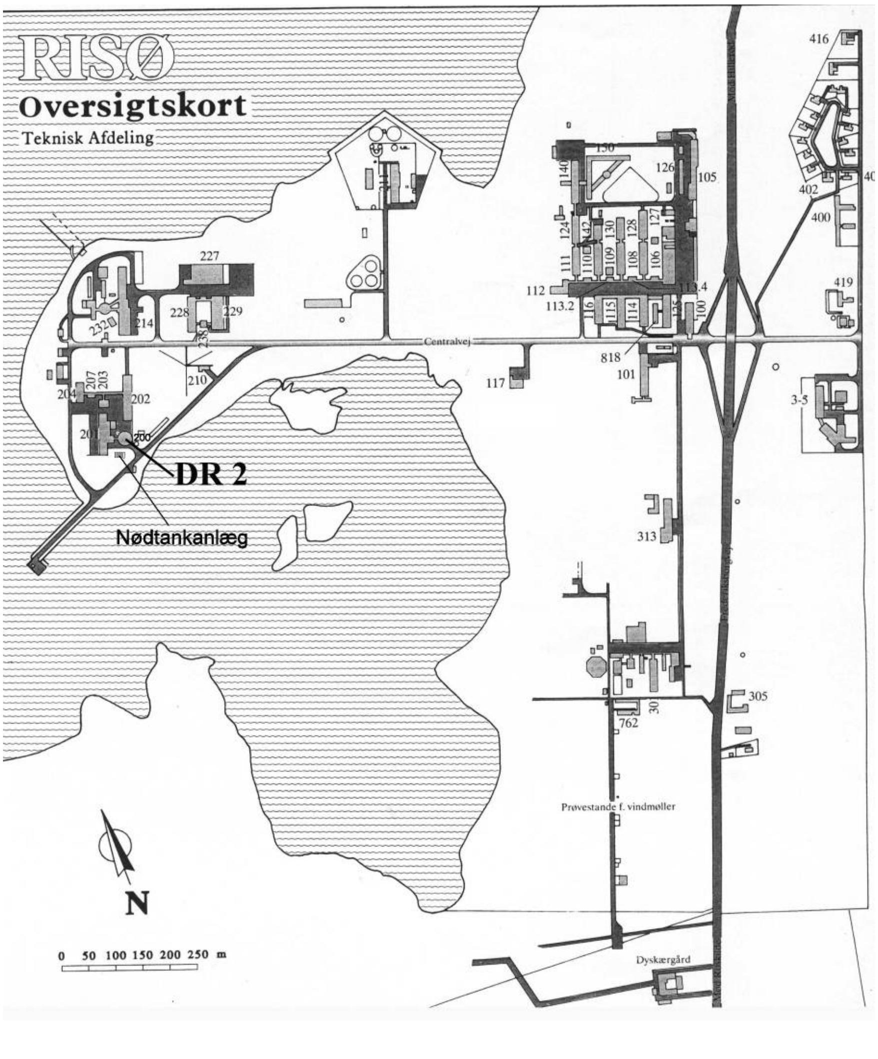

Figure 1. Map of Risoe, indicating the location of DR 2.

2.1 Reactor construction

Reactor DR 2 consists of the following elements:

- reactor block with a shielded tank, the reactor core, the thermal column and "the igloo" (ground floor);
- primary cooling circuit with a decay tank, heat exchangers, pumps and ion exchanger unit (basement); and
- secondary cooling circuit with a stand-by tank unit (basement and externally to the building).

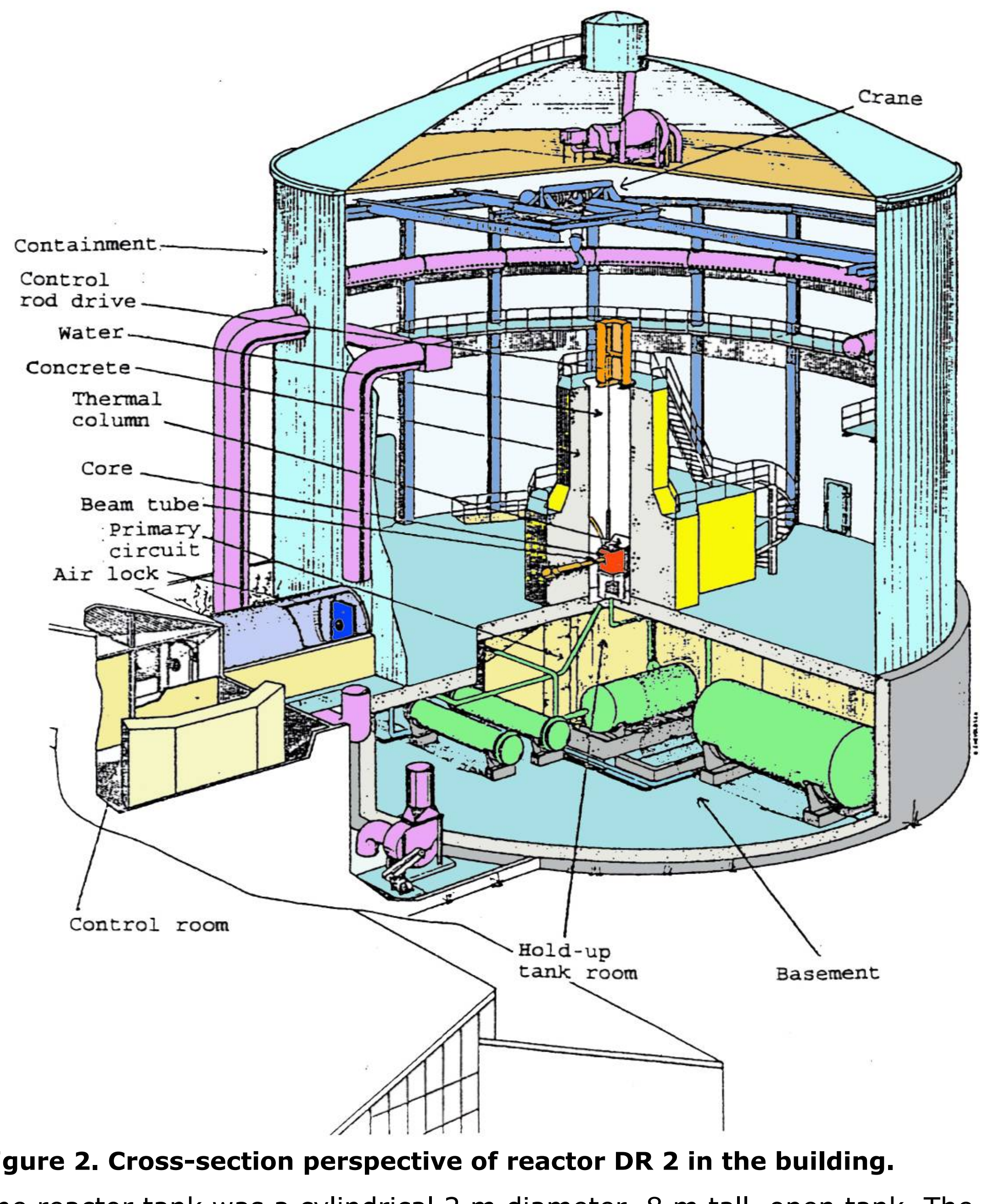

Figure 2. Cross-section perspective of reactor DR 2 in the building.

The reactor tank was a cylindrical 2 m diameter, 8 m tall, open tank. The reactor core was at the bottom of the tank, which was filled with deionized light water.

The lower part of the aluminium tank was encased by a biological shield in the form of an octagonal baryte concrete shield, roughly 2 m thick.

The reactor core consisted of 36 fuel elements with highly enriched uranium. In certain central elements the fuel plates had been removed and replaced by an aluminium box in which the vertical control rods (five safety rods and one regulation rod) with neutron-absorbing material were held.

The safety rods were suspended from electromagnets; in the event of power failure or excess neutron intensity, etc., these would be deactivated, which immediately dropped the safety rods into the core, thereby stopping the fission process.

During operation, the reactor tank was filled with de-ionized light water continuously purified in filters and ion exchanger units. The water ran from the reactor tank down through the elements to cool them. The water served several purposes:

- The water transferred heat from the fuel elements to the secondary cooling system by means of two heat exchangers located in the equipment basement. The primary cooling circuit was open at the reactor top and also had a closed pipe system in the equipment basement.

- The water acted as a moderator for decelerating the neutrons to thermal energy.

- The water acted as a reflector for the neutrons together with beryllium reflector elements and the thermal column. The beryllium elements were located in the outermost position on the reactor core grid plate along three sides, free of the thermal column.

- The water shielded upwards, which meant that radiation from the reactor core was strongly reduced at the top of the reactor. From the top of the reactor all moving of fuel elements and insertion of test units were made by means of remote-controlled tools (”fishing rods”) and a crane, when the reactor had been stopped.

All the fuel elements and control rods were removed when the reactor was closed down in 1975 [2]

Next to the reactor was a stand-by tank unit. The removal of the stand-by tank unit is described in section 5.6.

2.1.1 Biological shielding

The lower part of the aluminium tank was covered by a biological shield in the form of an octagonal baryte concrete shield, roughly 2 m thick. At the top, the thickness was 0.8 m, and the material was regular concrete.

The concrete structure contained three different types of concrete. The upper part, ’the chimney stack’, consisted of standard concrete with a density of about 2.5 tonnes/m^3. The lower part was made of baryte concrete with a density of about 3.5 tonnes/m^3. The shielding around the thermal column – “the igloo” was made of magnetite concrete with a similarly high density. The concrete structure contained no reinforcement iron bars other than the edge reinforcement netting, placed approx. 100 mm from the outer and inner surface towards the aluminium tank. However, the structure contained a large number of piping systems for cooling water for the reactor, cooling pipes for horizontal beam tubes, cable routings, etc.

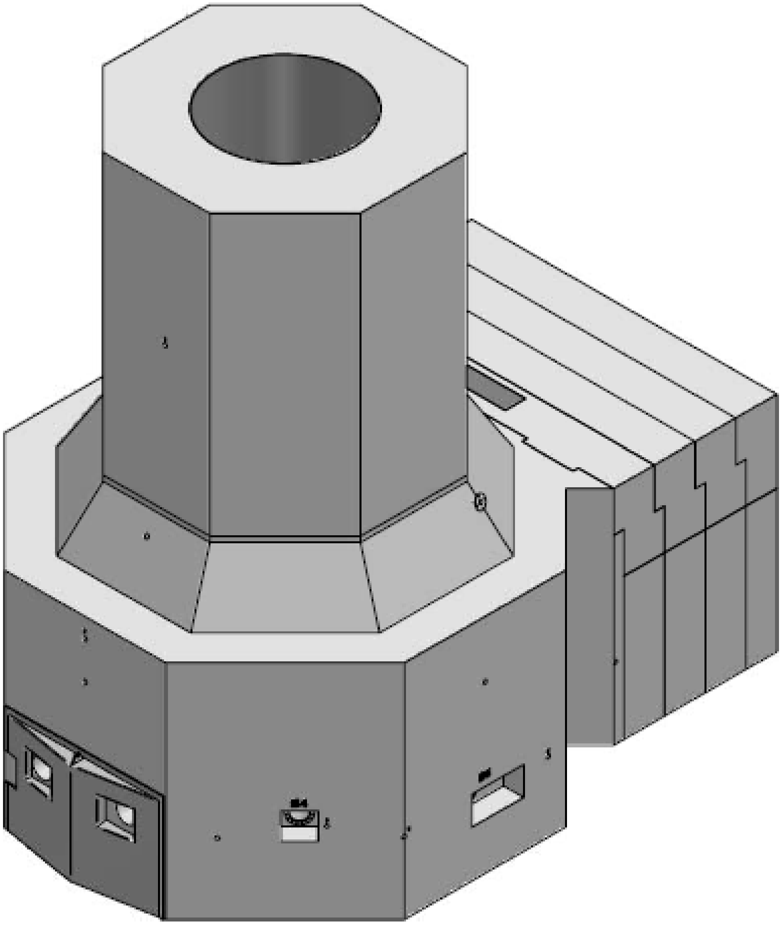

Figure 3. Elevated view of the DR 2 reactor's biological shield.

2.1.2 Experimental tubes

As described in more detail in section 5.2.3, DR 2 had eight horizontal beam tubes marked B1–B8, a through-going experimental tube marked T1-T2, eight curved irradiation tubes marked S1–S6 and R1–R2, as well as six instrument thimbles placed three-by-three on top of each other under the core.

2.1.3 Cooling circuit

The cooling circuit was placed in the basement under the reactor (cf. figures 2 and 4). The main elements of the circuit were two aluminium heat exchangers (cf. section 5.3.2). Before the cooling water was led to the heat exchangers placed in the equipment basement, it went through a holding tank (cf. section 5.3.1). This tank was placed in a shielded room directly under the reactor; it served to delay the water to allow ^{16}N to decay before the water reached the heat exchangers.

In addition, the cooling circuit contained a great many pipe connections (mainly aluminium) and pumps with connection to tank units in the building (2 for Waste, 1 for Storage, which were dismantled when the reactor was closed down in 1975), an ion exchanger unit (cf. section 5.3.3) and a stand-by tank unit placed outside the building (cf. section 5.6).

The overall structure of the secondary cooling system consisted of a piping system for the cooling tower placed south of the building. The cooling tower was shut down after the closing of the reactor [2].

A more detailed description of the individual parts of the reactor is given in the chapter on decommissioning activities (chap. 5). See also the DR 2 project description [2].

2.2 Characterisation of activity content

Prior to the launch of decommissioning activities, a characterisation of activity content was made in 1997–2003 and the radionuclides in the reactor were determined, which included location and quantities. This formed the necessary basis of information to give a description of the health physics conditions and a good overview of the parts that had been activated and the radionuclides contained in the materials concerned. This information was important for planning the decommissioning process. The results of the characterisation project were reported in detail in [11,2].

The tests performed showed the remaining measured activity in the reactor was distributed as shown in the table below.

Table 1. Measured activity levels

Component	Activity
Thermal column (graphite)	4 GBq ^{152}Eu
Thermal column (lead nose)	0.1 GBq ^{60}Co and 0.5 GBq ^{108m}Ag
Shielding plugs and lining tubes	1 GBq ^{60}Co
S beam tubes	0.1 GBq ^{60}Co

In addition, there was activity in the grid plate that held the fuel elements. The grid plate was a thick aluminium plate with holes for the fuel elements; at each hole was a stainless steel pin for controlling the elements. The grid plate was fixed with stainless steel bolts. It was not possible to do separate measurement of grid plate activity, but the estimate at the time was that this was the most active component in the reactor. The activity in the lead shielding around the instrument thimbles and the reactor tank, including the lead shield, was also not unequivocally determined, which is why the remaining activity in DR 2 was assumed to be in the magnitude of 5-10 GBq, mainly ^{60}Co and ^{152}Eu.

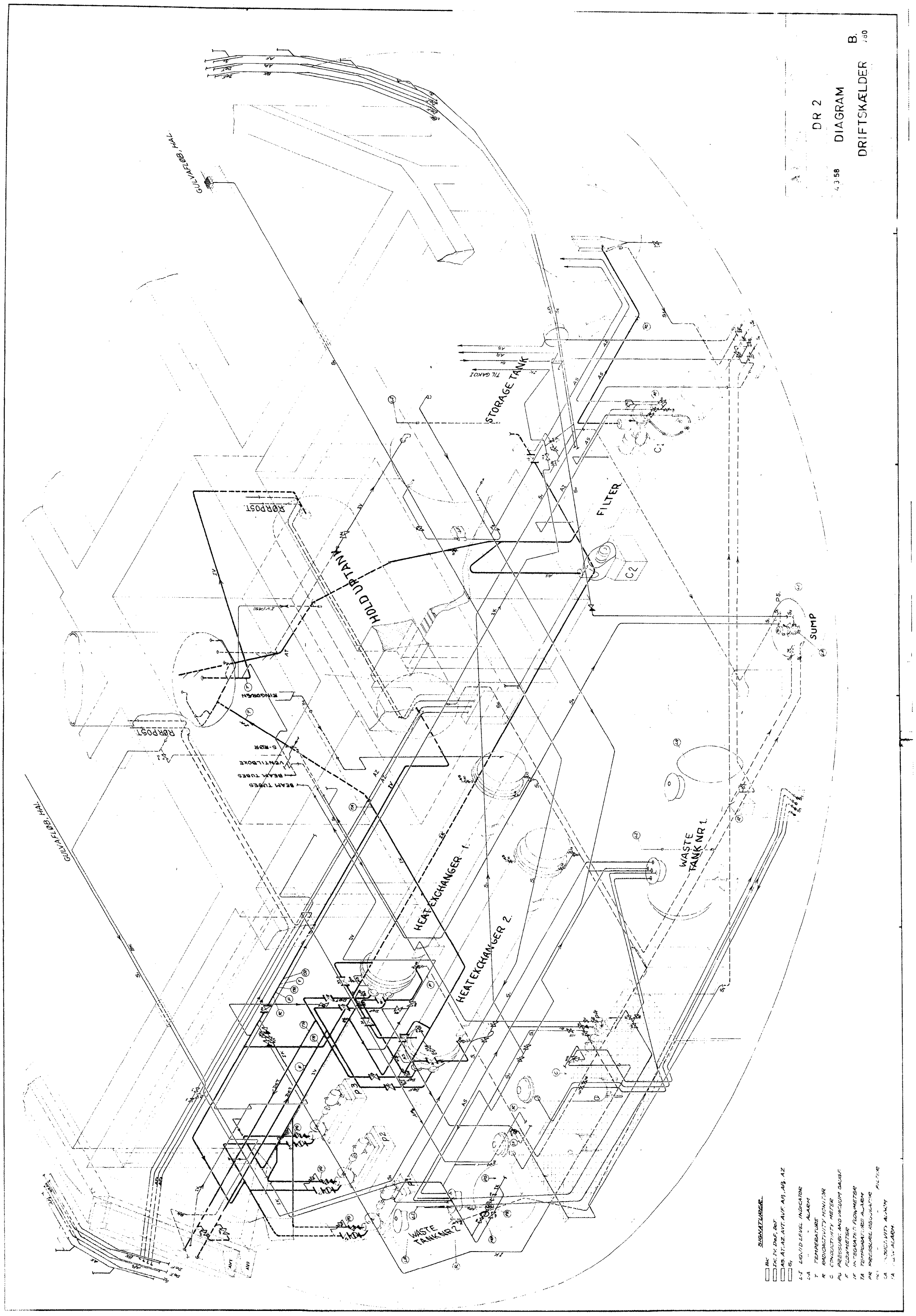

Figure 4. Diagram of engineering installations in the basement (original drawing).

The result of the radiation measurements made during characterisation of the reactor block and the thermal column is listed in figure 5. As is apparent, the highest radiation levels were measured in the area around the grid plate and the lead nose of the thermal column [2].

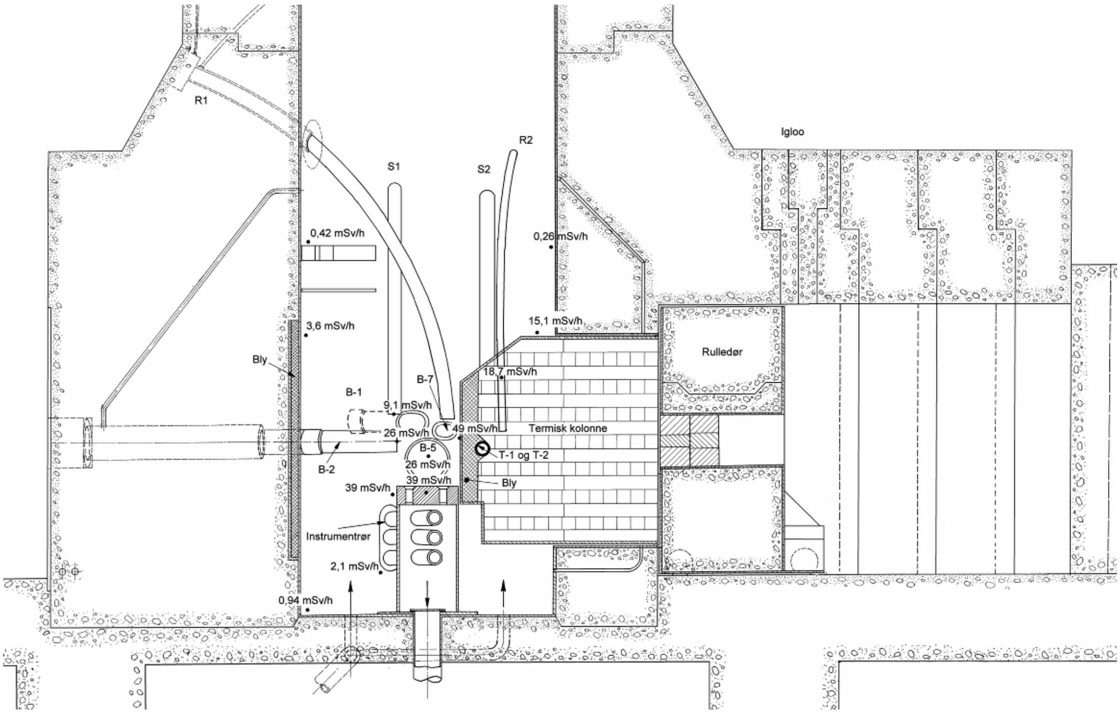

Figure 5. Cross-section of reactor block and thermal column showing the radiation levels measured with TL-dosimeters in the spring of 2001.

3 Decommissioning objectives and strategy

It was decided that the two reactors DR 1 and DR 2 would serve as learning experiences prior to the decommissioning of the remaining parts of the nuclear facilities, in particular DR 3. The decommissioning of DR 1 and DR 2 was planned for the period 2004 to mid-2009. The decommissioning of all the nuclear facilities is planned to continue until 2018.

The overall objective of decommissioning the nuclear facilities at RISOE is to reach a ”greenfield” level, thereby enabling the area and any remaining buildings to be used for other purposes without any restriction (as regard radioactivity). A more in-depth description of the decommissioning plans for the reactors and the nuclear facilities at RISOE is available in [1].

When the first draft general plan for decommissioning the nuclear facilities on the Risoe site had been prepared, the selection of methods for decommissioning all the nuclear facilities on the site began.

A much more detailed planning of the decommissioning of DR 2 was contained in the project description [2], which included the preparation of a budget to be approved by the Parliamentary Finance Committee. The project description was submitted to the nuclear supervisory authorities for approval.

The selection of the final methods and tools for the individual decommissioning works largely occurred in the course of the detailed preparation of these works. DD’s general procedure is to carry out as much of the dismantling work as possible using DD’s own staff, while external suppliers will only be used for works that involve low levels of radioactivity.

One consequence of this procedure was the plan to acquire rather costly wire-cutting tools for dismantling the more radioactive parts of the centre of the reactor. This solution would require the training of staff and prior tests and trial cuts; this would be time-consuming and cost-intensive. Consequently, this plan was abandoned, since skilful external contractors were expected to be able to carry out this task better, safer and quicker than DD’s own staff. This report will touch upon this subject and provide an overview of the deliberations made when selecting the most important tools and dismantling methods.

4 Radionuclides and clearance criteria

In the characterisation project [10], most of the existing radionuclides were identified. During decommissioning, only the pure β-emitters, ^{3}H and ^{14}C, were subsequently added to the list, see also section 5.3. These were identified by abrasion samples taken from the inside of the primary cooling system. The total list of identified radionuclides in DR 2 is given in table 2.

The detected radionuclides are subjected to clearance levels, shown in table 2, as given by the nuclear supervisory authorities.

Table 2. Detected radionuclides in DR 2 and their clearance levels

Radionuclide	Mass-specific clearance level (Bq/g)	Surface-specific clearance level (Bq/cm^2)
^{3}H	100	10000 (not used)
^{14}C	1	1000 (not used)
^{60}Co	0.1	1
^{133}Ba	0.1	1
^{137}Cs	0.1	1
^{152}Eu	0.1	1
^{154}Eu	0.1	1
^{235}U/^{238}U[1]	0.1	0.1/1

4.1 Clearance function

A function has been established under the Section for Radiation and Nuclear Safety to handle the clearance of items, buildings and land areas. The clearance function is a separate unit accredited in accordance with DS/EN ISO/IEC 17025:2005[2]. In connection with accreditation, a quality manual was prepared that describes all the procedures and instructions to be used when releasing items and buildings[3]. The next section gives a broad description of some of the important procedures from the quality manual.

[1] The uranium found comes from a uranium pilot project (after DR 2's closure), which on a "semi-industrial scale" served to test the technology for extracting uranium from ore coming from Greenland's Kvanefjeld.

[2] Accreditation number 488.

[3] Quality manual for Danish Decommissioning's clearance function, Per Hedemann Jensen.

4.2 Clearance procedures

A concept known as the clearance index has been introduced. This is defined as the relation between the measured activity concentration and the clearance level of a given radionuclide. An item can thus be cleared if the clearance index is below 1. If there are several types of radionuclides in an item, a summation formula is used. This summation formula also takes account of the uncertainties of the measurements to ensure that the calculated clearance index is always on the conservative side. The summation formula looks as follows:

$$FIM = \sum_i \left(\frac{C_i}{CLM_i} \right) + 1.65 \cdot \sqrt{\sum_i \left(\frac{u(C_i)}{CLM_i} \right)^2}$$

in which:

- *FIM* is the clearance index (mass-specific)

- C_i is the measured activity concentration for radionuclide *i*

- CLM_i is the clearance level for radionuclide *i* (mass-specific)

- $u(C_i)$ is the uncertainty of the activity concentration for radionuclide *i*

The use of the summation formula ensures that an item is 95% likely to be clearable. Measurements of a single item are allowed over max. 1000 kg.

Items that have smooth surfaces without indentations and that have not been neutron-activated can be cleared using surface contamination measurements. The clearance level for β-contamination (^{60}Co, ^{137}Cs) is 1 Bq/cm^2, while it is 0.1 Bq/cm^2 for α-contamination (actinides), cf. authority requirements in BfDA, chap. 7. For clearance by use of a contamination monitor a similar formula to the one above is used, in which *i* assumes the values α and β. Measurements of a single item are allowed over max. 1 m^2.

If the volume of an item is too big for testing its clearance in one measurement, samples can be drawn and measured separately. Subsequently, a statistical method is used to test for possible clearance. Two methods are used: One for a known distribution of activity (method A), and one for an even distribution of activity (method B). The use of method A means that samples will be drawn at the places in the item/system where activity is known to be the highest. If these samples can be cleared, the whole item/system can be cleared. In method B, a number of representative samples are drawn first. A statistical analysis of the measuring results and their uncertainties decides whether the item/system can be cleared immediately or whether additional sampling is required.

4.3 Document management

When an item is to be cleared, a number of documents are generated. In connection with a mass-specific clearance, the following documents are saved electronically: the generated measuring report, a spreadsheet with entered measuring results and uncertainties, as well as a clearance report. These are saved on DD's common drive and filing system. In addition, the clearance report is attached electronically to the item in DD's waste documentation system (ADS). All documents related to the clearance of an item are also saved in paper format in the clearance laboratory filing system.

A spreadsheet for mass-specific clearance calculates the clearance index on the basis of the above-mentioned formula, while choosing the nuclides to be included in the calculation. If within a given measuring time no activity is measured for a given nuclide that may be expected to be in the item, a "highest possible activity", PGA, is entered. PGA thus forms part of the calculation of the clearance index. The weight of the item is also entered in the spreadsheet. When everything has been entered and the clearance index is below 1, the sum of the measuring values, the uncertainty of the sum of the measuring values and the clearance index are transferred to the clearance report.

A clearance report contains information about the item that is cleared, its weight, the measuring instrument used and information about nuclides detected or not detected (where PGA forms part instead of a detected activity).

For surface-specific clearance with a contamination monitor, the filled-in spreadsheet(s) is/are saved together with the clearance report on DD's common drive and in the electronic filing system. The clearance report is attached to the item in ADS.

In a spreadsheet for surface-specific clearance, the measuring results for each part-area, corresponding to the detector area, are entered. Based on a summation formula, the spreadsheet calculates the clearance index. If the clearance index is below 1, the measuring result and the uncertainty of the measuring result are transferred to the clearance report together with the clearance index.

A clearance report for surface-specific clearance contains largely the same information as if it had been made for mass-specific clearance, the only difference being that the weight is replaced by the area of the item.

5 Decommissioning work

The decommissioning work started in 2006 and ended in 2008. Basically, DD carried out all the decommissioning work itself, wherever activated and contaminated items were involved. In special cases, where DD was not in possession of the necessary expertise or equipment, the technical specialists required were contracted.

Figure 6. Reactor block and project manager at the commencement of the decommissioning process (June 2006). Access apertures for experiment tubes are concealed.

When the reactor was closed down in 1975, all apertures were shut and covered up.

The decommissioning work included stripping of the reactor before the reactor block itself was demolished; this included biological shielding. The decommissioning works were the following:

- re-establishment of ventilation in the building;
- Stripping of the reactor block:
    - removal of items from the igloo;
    - removal of B, R, S, T-tubes and instrument thimbles, including shielding plugs;
    - removal of the thermal column;
    - removal of the grid plate;
- dismantling of cooling circuit and ion exchanger unit (basement);
- demolishing of the reactor block and lining tubes (liners);
- Removal of stand-by tank unit.

In parallel with the stripping, the demolishment preparations started with making drawings of the structure.

5.1 Ventilation

Prior to the commencement of the decommissioning works, it was decided to renovate the ventilation system in the building [2]. This started with control measurements of the existing ventilation system installations in the basement of the building.

5.1.1 Health physics measurements in the ventilation room

Contamination measurements and dose rate measurements were made in the ventilation room in DR 2's basement (pressure chamber, etc.) with a view to dismantling/converting the ventilation system in the room, cf. below.

Random-sample measurements were taken of regular surfaces using a contamination monitor of type CoMo 170 calibrated for ^{60}Co; none of the levels measured exceeded the background level for the area.

Seven smear samples were taken (paper smear tests), divided between the two pressure chambers. The analysis results were as follows:

Maximum α-contamination: 3.6 Bq/m^2± 1.8 Bq

Maximum β-contamination: 12.8 Bq/m^2 ± 6.4 Bq

The maximum values were measured on a smear test made through an attic hatch in the back pressure chamber. Subsequently, four smear tests were made from selected locations in the ventilation room; no levels above the background level were measured.

The dose rates in the rooms were measured; the maximum levels measured were < 0.1 μSv/h.

Based on the measurements and analyses made, it was concluded that the ventilation parts could be dismantled and removed from the basement room and that this work could be carried out without any additional health physics precautions. However, while this work was being done, ongoing control measurements were made on removed items.

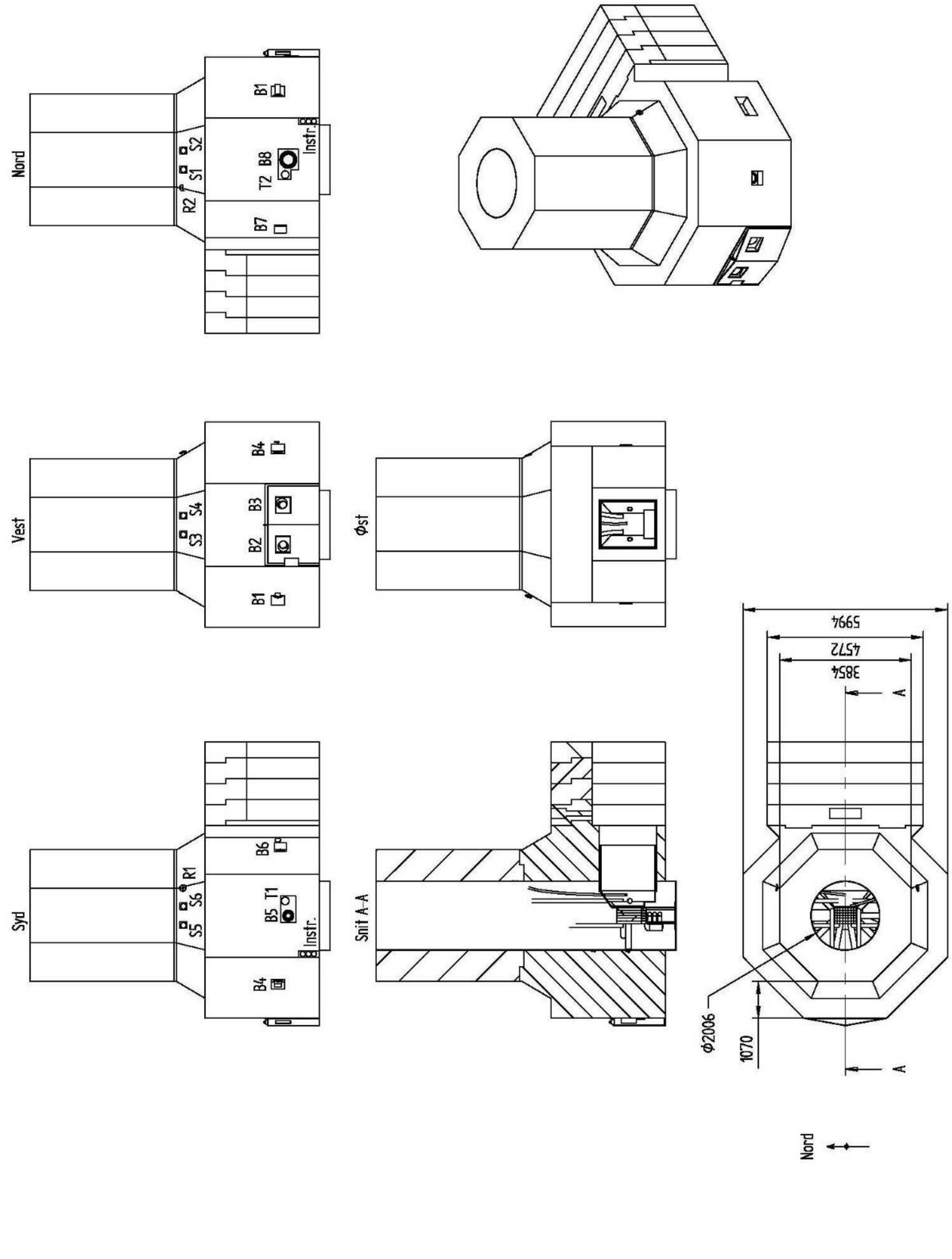

Figure 7. Drawings of the reactor block at the start of decommissioning.

5.1.2 Dismantling of the old ventilation system

The old ventilation system was dismantled largely by DD's own staff. The parts removed included filters, tanks, pipe sections and valves, including very heavy Gako valves. The last-mentioned items in particular represented a challenge, since the largest of these valves were located at the back of the pressure chamber. So the assistance of external specialists was required to move heavy equipment.

First a hole was cut in the pressure chamber using a cutting torch. After the valves had been dismantled, they were lifted and pulled out with the use of ingenuity, muscles and a mobile crane.

Figure 8. Preparing to remove a Gako valve.

Figure 9. Removing a Gako valve.

Control measurements were made on all accessible surfaces of the items removed before these items were placed in a transport container outside the building. The container was not removed from the area until this was approved by the project manager and the health physics technician. All parts were disposed of as scrap steel after their clearance.

5.1.3 New ventilation system

The ventilation system was converted to look like the sketch in figure 10 below.

In brief, the conversion consisted in fitting a duct with a regulation damper on the fresh-air duct after the motor damper inside the pressure chamber; furthermore, the recirculation block was removed and the duct was fitted with a regulation damper. Subsequently, a connection was established to the fresh air duct in that the two converge in a T-section.

The fresh air / recirculated air is carried in a duct to the heating surface and from there to ventilator 2 and into the reactor hall. Injection and recirculation from ventilator 1 are both covered up in the reactor hall. When the system is running, it can now be regulated to obtain a negative pressure of 30-60 Pa in the hall.

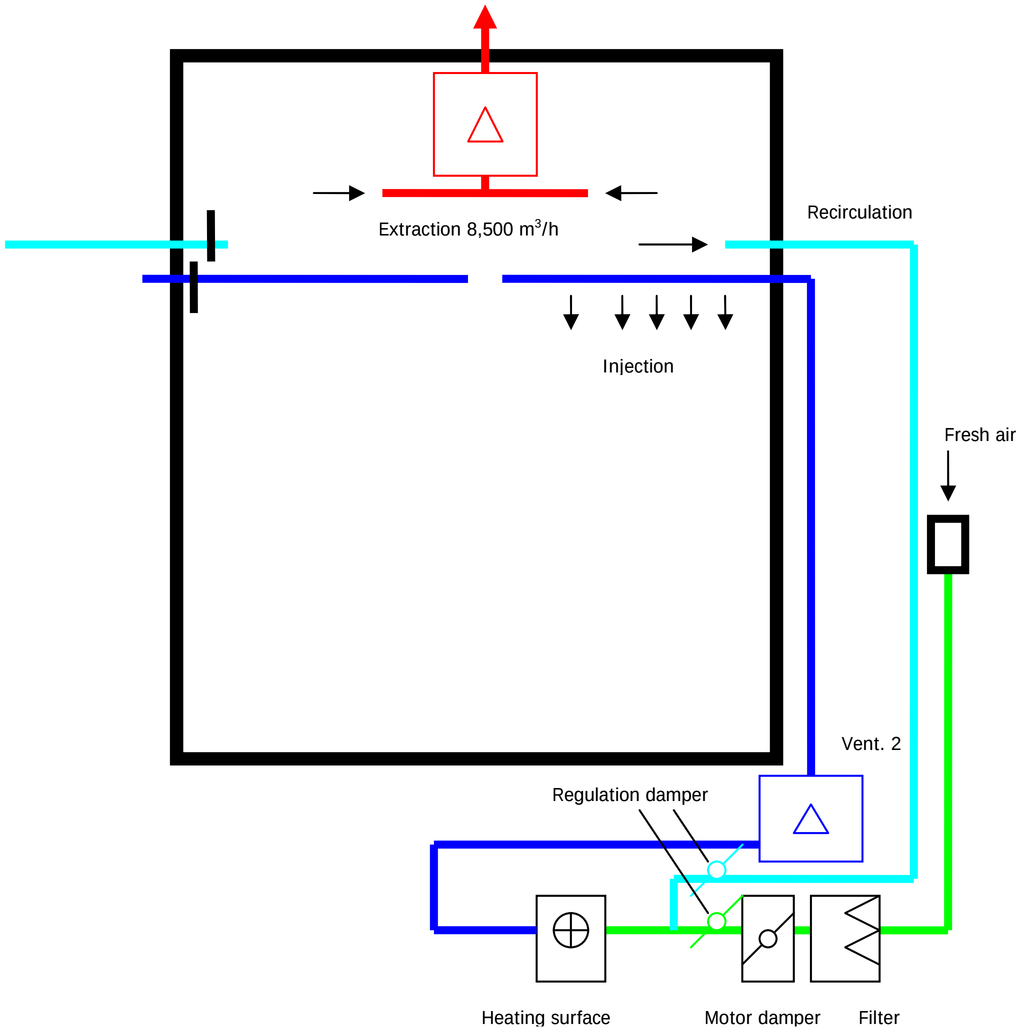

Figure10. Skeleton diagram of new ventilation system

5.2 Stripping of the reactor block

Before the stripping of the reactor and the commencement of the subsequent work, the hall was laid out keeping in mind that a number of facilities would have to be easily accessible, e.g. the possibility of crane access and the shielding of different areas had to be catered for. Consequently, a need was identified to establish the following, among other things:

- shielding for 2-3 separate transport containers;
- shielded area for making control measurements of items;
- areas for placing tools and other equipment;
- lock areas classified for blue and yellow waste, respectively (aluminium containers) and a lock area for containers for further transport away from the hall.

Consequently, a layout plan was drawn that formed the basis for laying out the hall and dividing it into classification zones, cf. figure 11.

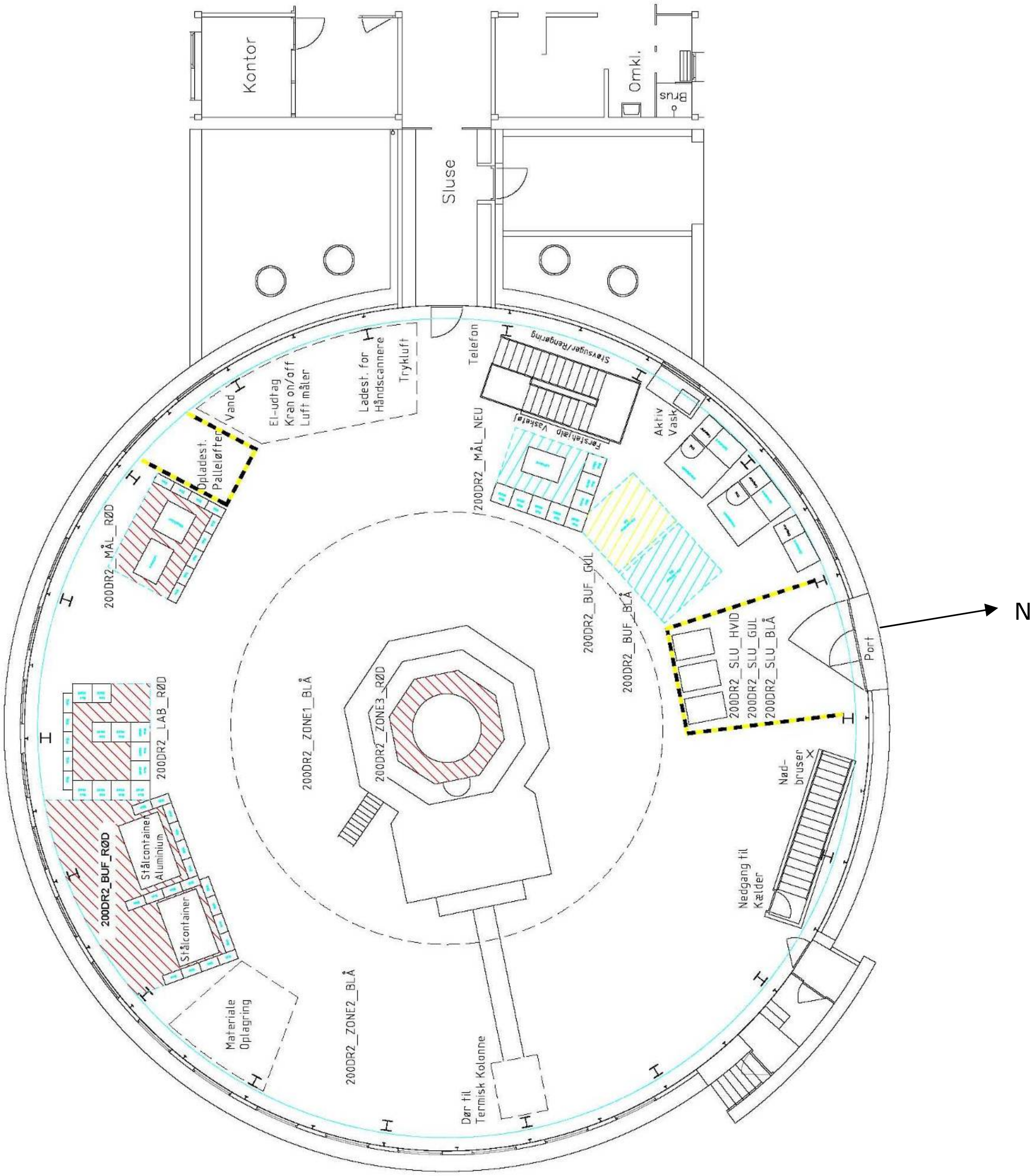

Figure 11. Logistics plan for the DR 2 hall during stripping.

5.2.1 Emptying of the igloo

Access to the thermal column was ensured by the ring crane lifting off the two large concrete blocks (magnetite concrete) at the end of the igloo. Subsequently, the large, electrically operated sliding door could be rolled out on rails.

The igloo contained various components stored in connection with the shutting down of the reactor in 1975.

Initially, an overview of the contents was obtained and on this basis a decision was made regarding the sequence and method of removing the individual components.

Since the igloo contents had been stored for many years, it was expected that the items might be pretty dusty and the work was planned accordingly – i.e. the individual components were moved one at a time and vacuumed just outside the igloo. Subsequently, a first control measurement was made. It was then decided what was going to happen with the individual component. No contaminated dust was found.

Control measurements were made on all elements and registered in the waste documentation system, ADS.

Figure 12. Items stored in the igloo.

When the igloo was opened, various contaminated auxiliary tools and other items from the operating period, such as graphite from the thermal column, dummy plugs from horizontal beam tubes, etc., were found. These are described in "The DR 2 Project" [10].

5.2.1.1 <u>Sliding door</u>

After the power was reconnected, the door turned out to be still operational. The sliding door could thus be used until the igloo had been emptied and the removal of the thermal column was to be started.

The central part of the sliding door contained a plug that was used for removing the central graphite stringers in the thermal column.

The sliding door was made from heavy steel and magnetite concrete. The total weight of the door was about 16 tonnes. Control measurements showed that the central part around the plug had been activated while DR 2 was in operation. It was thus decided that the sliding door would subsequently be partitioned and the activated parts removed. It is expected that only a minor part (< 1 tonne) will have to be deposited as active waste and that the remaining part can be removed as cleared waste. This work has been planned for subsequent execution, cf. section 11.2.

Figure 13. The sliding door is run out. At the centre is the plug for removing graphite for the thermal column. The rail system can be glimpsed at the bottom.

5.2.1.2 <u>Contamination and dose-rate measurements in the igloo</u>

After being emptied, the igloo was vacuumed, following which various informative contamination and dose rate measurements were made in the igloo[4].

The dose rate in the igloo was measured at <1 µSv/h – however, a dose rate of 10 µSv/h was measured at the graphite placed in the sliding door plug hole.

[4] Memo of 8 November 2006, *Contamination and dose rate measurements in the igloo - DR2*

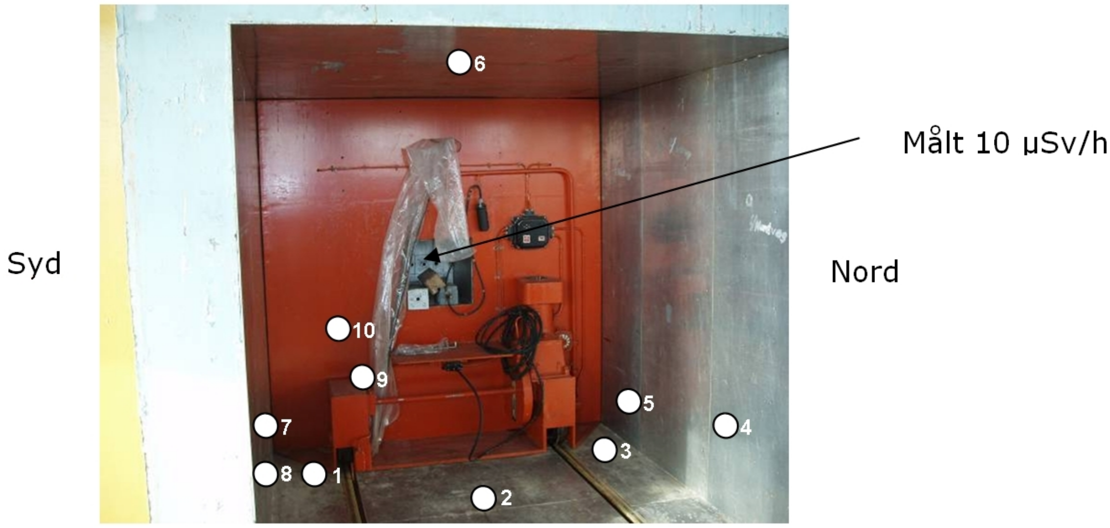

Figure 14. Measurements in the igloo before the sliding door was removed

Table 3. Measuring results of smear tests

Point	α Bq/m²	β Bq/m²
1 Floor, south	0.4	16.8
2 Floor, middle	0.4	10.9
3 Floor, north	0.5	11.8
4 Wall, northeast	0.4 (MDA)	5.5
5 Wall, northwest	0.3 (MDA)	53.2
6 Ceiling	0.5	7.8
7 Wall, southwest	0.3 (MDA)	8.3
8 Wall, southeast	0.6	5.9
9 Horizontal surface, back wall	0.2	11.8
10 Back wall	0.3	5.2

MDA is Minimum Detectable Activity, so it represents the maximum possible activity in the smear test.

On the graphite in the sliding door plug hole, a dose rate of 40 µSv/h was measured on the inside (towards the thermal column). The graphite was all in an aluminium plug and was removed and placed in a shielded location for subsequent packing into a container.

The contamination measurements consisted of smear tests taken at ten locations (cf. figure 14 and table 3).

5.2.2 Removal of igloo units

The igloo was made in the form of separate concrete blocks, so it was possible to remove it in twelve whole elements and the concrete door in two elements. All blocks had in-cast threaded pipes for lifting rings. The blocks had been designed for removal, but had not actually been moved before.

When the blocks were to be dismantled – some of them weighed 12 tonnes a piece – it turned out in a couple instances that they could not be immediately separated into individual blocks. This gave cause for concern as regards the horizontal overhead blocks, which together weighed more than 24 tonnes (2 blocks). Since the maximum lifting capacity of the crane in the hall is 15 tonnes, it was not possible to lift away the blocks.

Jacks were used to help solve the problem. Also, the blocks were cracked open by means of electric concrete hammers. In one case following the cracking of a block, the entire lifting capacity of the crane had to be combined with three 20-tonne jacks in order to take the blocks apart.

It was found that a combination of wear and tear, the surface treatment used on the concrete blocks initially and the subsequent use of the building for other purposes [2] had led to the substantial adhesion between the blocks. However, eventually the blocks were removed, measured with contamination monitors for clearance, cf. the Clearance Function Quality Manual, and disposed of as normal building waste for reuse.

5.2.3 Removal of B, S, R, T and instrument thimbles

As is apparent in figure 15, DR 2 had eight horizontal beam tubes marked B1–B8, one through-going experimental tube marked T1-T2, eight curved irradiation tubes marked S1– S6 and R1–R2, as well as six instrument thimbles placed three-by-three on top of each other under the core.

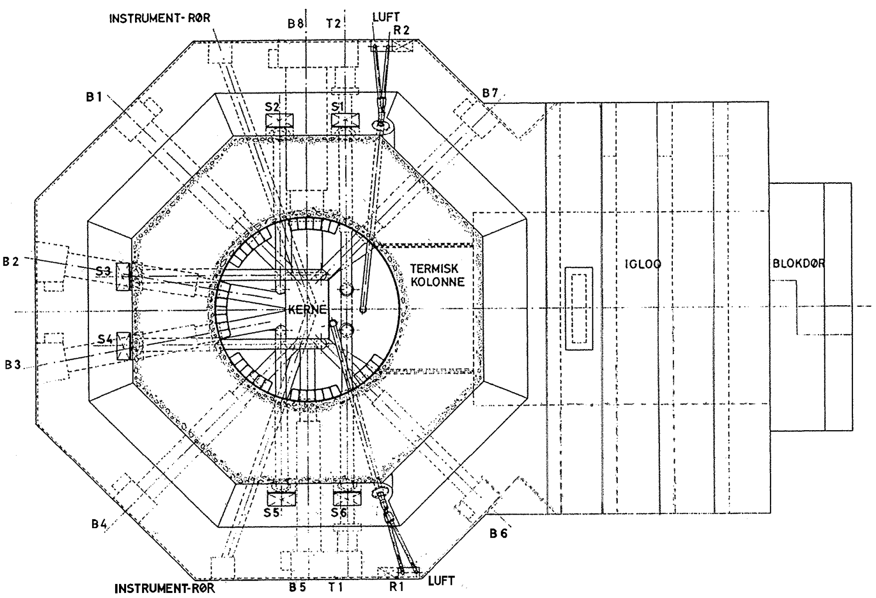

Figure 15. Horizontal cross-section through reactor DR 2.

Decommissioning of the experimental tubes consisted of removal, partitioning and storage (temporary) of all the above-mentioned tubes. This work was carried out from early April 2006 and lasted until late September. The dose rates to which reference is made below were all obtained from Povl L. Ølgaard's "The DR-2 Project" [10].

The location of the different tubes can be seen from the above cross-section, and their location in the reactor tank is apparent from figure 16. The T-tubes were horizontal leading straight to the thermal column and are not visible in figure 16, since they are underneath the other tubes. Also, the instrument thimbles are not shown, since they were covered by lead casings and located under the grid plate.

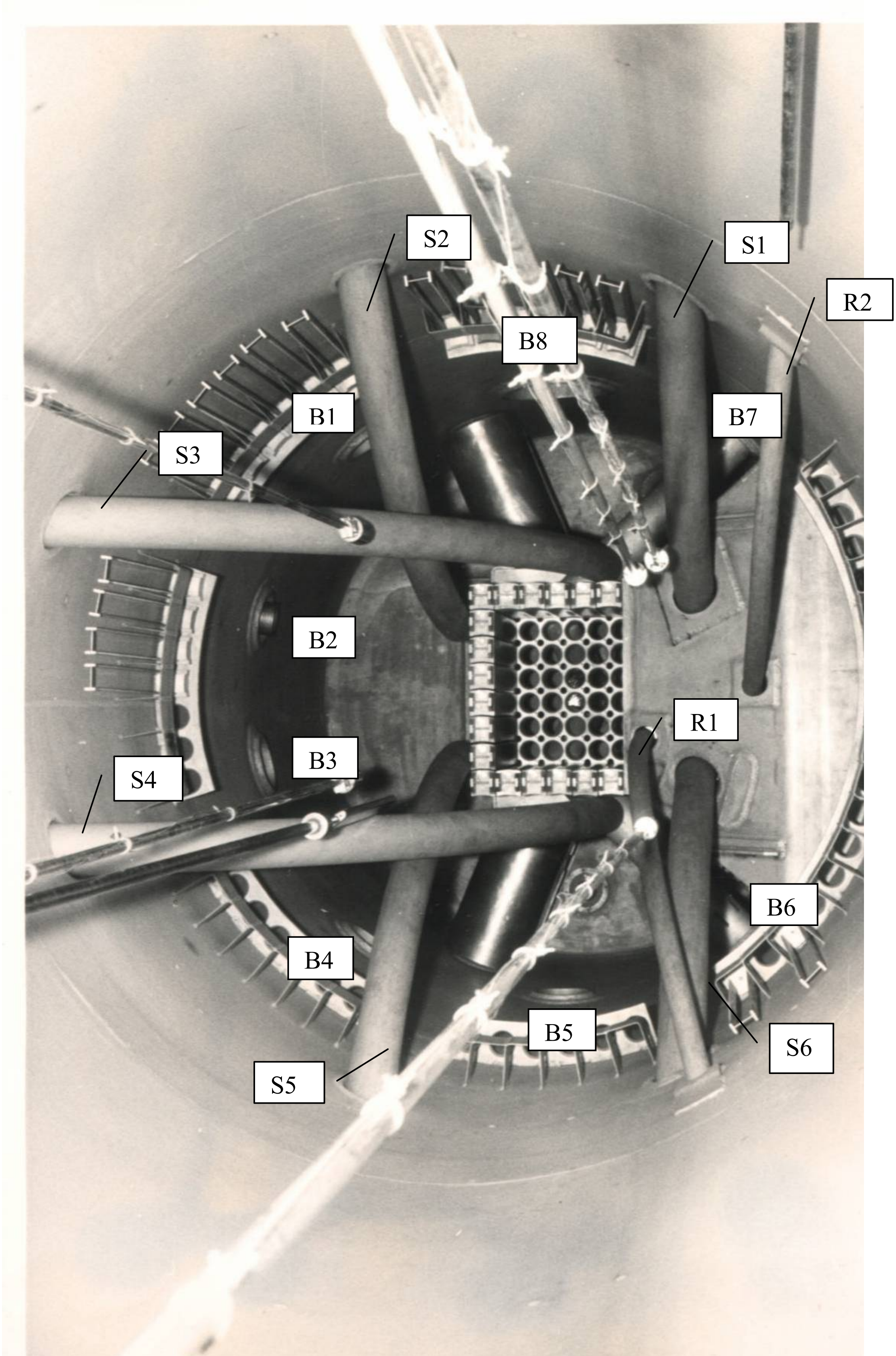

Figure 16. Overview of installations in the reactor tank.

5.2.3.1 S-tubes

Description

On the reactor block balcony were six irradiation tubes, S-1 to S-6, composed of aluminium tubes, with an approximate diameter of 11 cm and a wall thickness of 6 mm. The S-tubes were fitted in the concrete in linings. S-2 and S-5 were taken out and measured in connection with the DR 2 characterisation project in December 2001.

Radiation

In characterisation, 600 μSv/h was measured at the bottom surface of S-2, declining to half of that level at 40 cm distance from the bottom. The total activity of the six S-tubes was assessed to be approx. 0.1 GBq.

Figure 17. Removal of S-5 tube.

5.2.3.2 R-tubes

Description

Accessed from the reactor balcony were also two pneumatic tubes, R-1 and R-2. These tubes were made of aluminium and their diameter was 5.7 cm. R-1 went from the lead nose on the thermal column to the outside of the concrete shield. R-2 went from the graphite in the thermal column to the outside of the concrete shield. R-1 was soon taken out of operation and used as a water level gauge in the tank during the service life of the tank.

Radiation

The R-tubes were not taken out for the characterisation project, but when stripping was done the maximum dose rate was measured at 0.6 mSv/h[5].

5.2.3.3 B-tubes

Description

The reactor had eight beam tubes, B-1 to B-8. B-1 to B-5 had a nominal diameter of 6”, B-6 and B-7 4”, while B-8 was 13”.

The beam tubes were set in an aluminium lining bolted to the inside of the vestibule box and extended to the core of the reactor. The lining was in turn placed in a bushing tube, also of aluminium. The bushing tube was attached to the concrete and its reach was from the inner wall of the vestibule box just into the reactor tank.

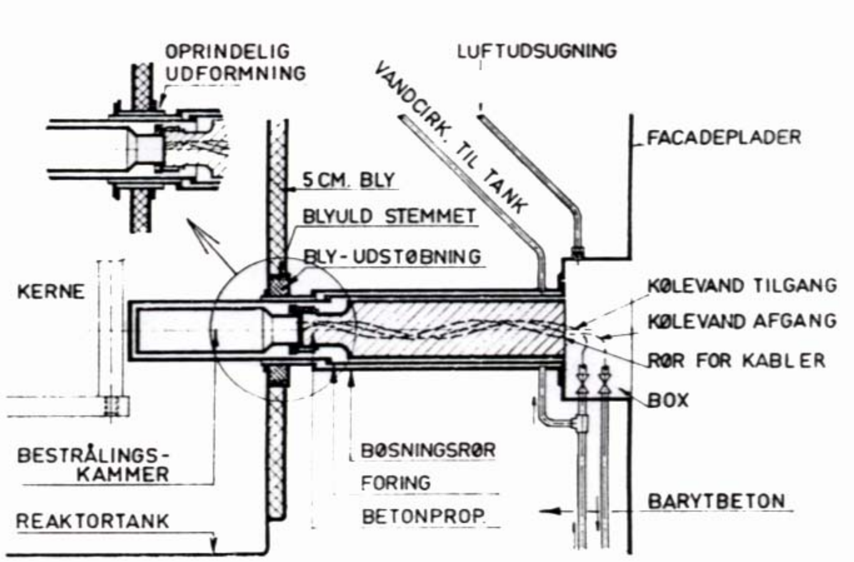

Figure 18. Basic design of horizontal beam tubes.

The basic structure of the horizontal beam tubes is shown in figure 18.

B-1 to B-7 contained different beam tubes, depending on the nature of the experiments made, while B-8 was never in use.

Beam tubes B-3 and B-5 were taken out for the characterisation project. B-3’s lining was taken out, but the removal of B-5’s lining and of B-8 was abandoned.

Radiation

In characterisation, 600 µSv/h was measured at the bottom surface of B-5 declining to 30 µSv/h at a distance of 1 metre from the end surface. B-3’s lining tube was also taken out; 26 µSv/h was measured at a distance of 1 metre from the end surface. In regard to both B-3’s and B-5’s linings and beam tubes, the radiation level at 70-80 cm from the inside end was the same as the background radiation level.

[5] Memo of 1 June 2006, *Thursday, 1 June 2006 - R2*

For the characterisation, the total activity of the eight B-tubes with linings was estimated to be approx. 1 GBq, although with quite some uncertainty.

Figure 19. Removing the B-3 tube (photo from the characterisation project).

5.2.3.4 T-tubes

Description

The reactor had two through-going experimental tubes, T-1 and T-2. These tubes ran through the thermal column behind the lead nose, thus being close to the core. The T-tubes sat in an aluminium lining bolted to the inside of the vestibule box. The tubes were used for radiation experiments of short duration, where the samples were moved in and out with the use of pneumatics.

In the characterisation project, beam tubes T-1 and T-2 were taken out and the radiation level was measured. The pneumatic system was divided, so that the inner part was stored in a drum, while the outer part was stored in the experiment basement. Finally, the plugs were reinstalled.

Radiation

The activity measurements were reported in "The DR 2 Project" by Povl L. Ølgaard, page 49 [10].

Table 4. Activity in through-going experimental tubes

	^{60}Co	^{152}Eu	^{137}Cs
	(MBq)	(MBq)	(MBq)
T-1, outer shielding plugs	0.82		0.003
T-1, inner shielding plugs	0.45		
T-2, inner shielding plugs	0.20		
Pressurized air system	2.41	0.16	0.04

Figure 20. Removing the T-1 tube.

5.2.3.5 Instrument thimbles

Description

There were six instrument thimbles in the reactor structure. They were located in threes at the north and south side of the reactor, respectively, from where they reach into the centre of the tank under the grid plate.

The aluminium thimbles had a diameter of approx. 11 cm with a wall thickness of 6 mm and a length of 2.8 m. The thimbles were fitted with an ion chamber at the tip. The ion chambers were removed back when the reactor was closed down and placed in the igloo (cf. also section 5.2.1).

Radiation

In the characterisation project [10] the three linings were taken out and the dose rate was measured. 20 mSv/h was measured at the core, declining to 100 µSv/h at the start of the concrete shield and ending with 2 µSv/h on the outside, at the vestibule box.

Figure 21. Instrument thimble

5.2.3.6 Dismantling and partitioning of experimental tubes

The removal and partitioning of experimental tubes was made according to the following guidelines laid down in a work schedule:

- the cover plates had to be released from the concrete shield;
- the radiation level had to be measured continuously during removal;
- bolts in flange were loosened;
- tubes were pulled out using a crane and lifting rods;
- the tubes were cut into one-metre sections and flattened in a hydraulic press;
- depending on the radiation level, the cut-off section was stored in a steel container or stored in an aluminium container for subsequent clearance measuring in the Clearance laboratory;
- samples were taken for the A-laboratory;
- data for the waste items were entered in the waste documentation system, ADS.

All activated parts of the experimental tubes were partitioned and placed in DD’s steel container, which was taken to the Intermediate Storage facility.

The partitioning of S- and R-tubes was made behind the shielding by cutting off the activated parts and dumping them straight into a steel container by means of remote-controlled hydraulic shears (figure 22).

Figure 22. Placement of remote-controlled shear above container. A camera has been mounted on the shears themselves. The monitor is outside the shielding.

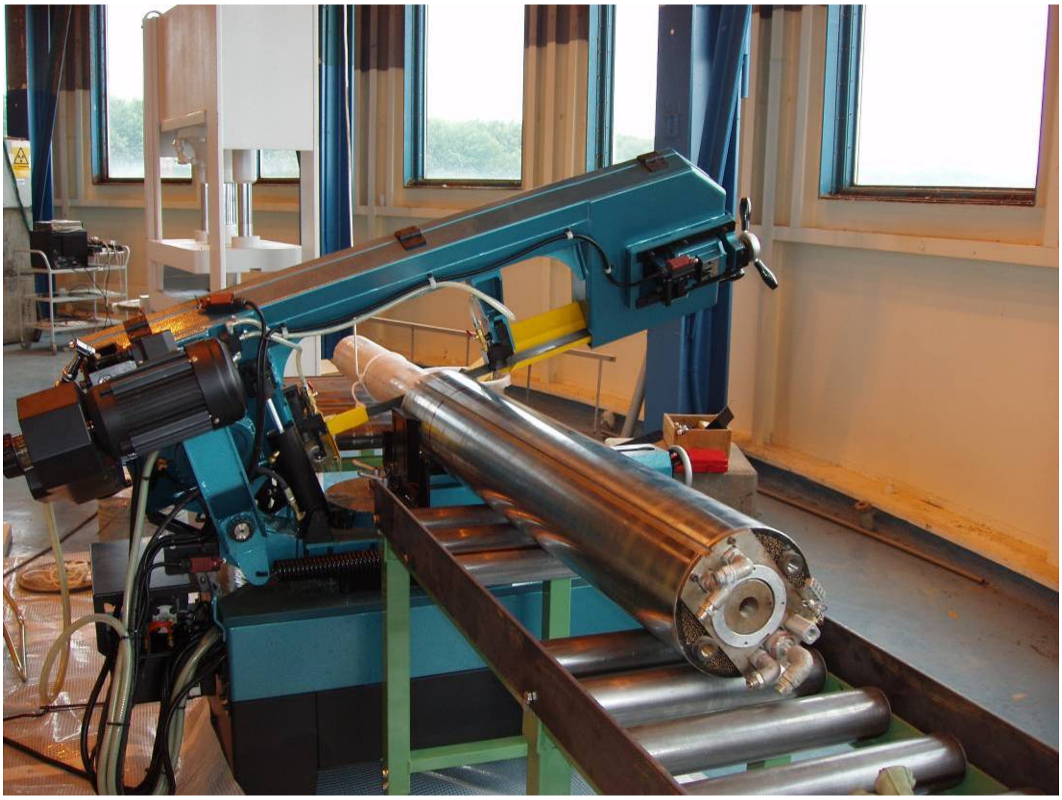

Figure 23. Partitioning of a B-tube in an automated band saw.

Large tubes, such as B-tubes, were partitioned by means of an automated band saw. Since the tubes were quite heavy, a roller table was used. The activated parts were placed by means of a lifting sling and could thus be transferred to DD's steel containers straight from the saw.

A few of the B-tube plugs had a combination of steel/concrete/steel balls or resin/steel balls, so they could not be partitioned any further with the tools that DD had immediate access to. Because of the relatively small amount of waste and in order to avoid unnecessary radiation doses from what might have been a complicated further partitioning it was decided to use the plugs in connection with the packing and shielding of other activated items from the reactors in DD's containers (cf. figure 34).

5.2.3.7 Doses when B-, S-, R-, T-tubes and instrument thimbles were removed

All tubes were taken out while paying great attention to the significance of time and distance in regard to reducing doses. As described above, tools were developed that could be handled at a distance from the radioactive items. The accumulated collective dose for the removal of instrument and experimental tubes was 6 man-μSv, cf. chap.9. In addition, wrist doses of 0.2 mSv were measured for two technicians (in both cases for both hands).

5.2.4 Removal of the thermal column

5.2.4.1 Removal of graphite stringers

The thermal column contained approx. 200 graphite stringers, most of which were one metre long, with a total weight of about four tonnes. It was necessary to remove the graphite in order access to lead nose of the column.

Access for measuring the radiation level could be ensured from the graphite on the outside, but there were concerns that the inner part of the stringers would give off significant radiation levels. For this reason, the decision was made to minimise staff handling of the graphite material.

Figure 24. Thermal column with graphite; radiation level is measured.

At the entrance to the igloo (from the outside of the unit) a dose rate of 10 μSv/h was measured.

A survey measurement was made in front of the graphite pile; the maximum dose rate here was measured at 250 μSv/h (at the centre of the graphite construction at approx. 1 cm's distance). In addition, measurements were taken on both the south and the north side (to the left and right, respectively, in figure 24) of the graphite construction at approx. 50 cm's distance; the maximum dose rate here was 50 μSv/h.[6]

Furthermore, it was ascertained that, in addition to taking account of radiation levels and the necessary shielding measures for removing the thermal column, DD also needed to take account of the possibility of contaminated/activated graphite dust. Consequently, the use of breathing masks was mandatory during work and extra cleaning was carried out subsequently.

Access to the thermal column was via the igloo. For easier access and handling of activated items from the column, including graphite, the ele-

[6] Memo of 8 November 2006, *Contamination and dose rate measurements in igloo - DR2.*

vated igloo blocks were removed. The vertical blocks were maintained, in order to act as shielding when the work was performed. This meant that the ring crane of the hall could be used for removing the graphite stringers without any obstacles.

To begin with, a work area was established in the DR 2 hall with suitable shielding of containers, shielding around the thermal column and with the possibility of remote-controlling equipment and handling items. Control and monitoring were possible e.g. directly from the reactor block balcony.

Figure 25. Graphite stringers, cross bond visible, and cables for thermocouples in lead nose exposed.

Figure 26. Set-up for shielding and remote-controlled handling of graphite removal and container packing.

In connection with other previous works, such as the DR 1 project, DD had developed special pressure tools with vacuum suction discs for lifting and removing graphite and other material. So this equipment was already available at DD and only needed a bit of maintenance and adjustment to be used for moving the graphite stringers.

The work included the removal of all graphite stringers to ear-marked containers, including measuring and recording of each stringer.[7] This recording plus subsequent experiments made on selected stringers served the purpose of identifying the graphite to be annealed of Wigner energy before being placed in the final repository.

For lifting the graphite stringers, the pressure tools were fitted on an aluminium bar. An extender was also fitted with a pressure device to pull the stringers out of the thermal column. The removal of the stringers by means of the suction disc devices turned out to be effective, so the work was carried out safely and in accordance with the work schedule.

Figure 27. A graphite stringer being removed by using a vacuum lifting device and placed in a DD steel container.

To DD steel containers were filled, corresponding to just over 5 m^3. Upon removal, the graphite was divided before going to the containers, so that the outermost one-metre layer was packed in one container, while the innermost layer of approx. one metre was packed separately.

When removing and recording, a dose rate on the stringers of up to 800 µSv/h was measured. Obviously, this fact had to be taken into consideration in the further work described below.

5.2.4.2 Wigner energy in the graphite

When the DR 2 reactor was to be dismantled, the following question arose: how much Wigner energy is stored in the thermal column in DR 2,

[7] Spreadsheet of 23 March 2007, *1207 Graphite Recording.xls.*

and was it going to be necessary to anneal all or part of the graphite before placing it in a repository? For this reason experiments with annealing of graphite were carried out in June, July and September 2007 and subsequently reported (Appendix 2).

The examination was based on heating selected pieces of graphite to 350°C. Any additional temperature increase would be attributable to Wigner energy.

The results clearly show that there is a considerable amount of Wigner energy at around 400 J/g stored in the innermost, central part of the thermal column, while the Wigner energy in the outer layers is close to zero. Quick release of 400 J/g would result in a temperature increase of about 280–290°C. At the centre of the thermal column, the temperature increase could be considerably lower, only 40–45°C.

The acceptable energy release in a repository for radioactive waste is currently unknown. To be on the safe side, it would seem appropriate to anneal the inner half of the graphite from the thermal column in DR 2 to 350–400°C, i.e. the part of the column that corresponds to the inside longitudinal girder (~ 2 tonnes, 2.5 m^3). This work will be carried out by DD later on, once the relevant facilities have been established, cf. section 11.2.

5.2.4.3 Cutting off the lead nose from the thermal column

The structures in the reactor tank were all made of aluminium, including the thermal column box and the grid plate and its rack.

The radiation level measured on the back of the lead nose – towards the igloo – was about 2 mSv/h after the graphite stringers had been removed. It was known from previous measurements that the highest radiation level in the reactor tank was just in front of the lead nose above the grid plate, where the level was approx. 60 mSv/h.[8]

Most of the radiation was deemed to be coming from the grid plate; however, a considerable part would also be expected to be coming from the lead nose itself, given that it is immediately adjacent to the reactor core. Based on camera and video inspection of the structures in the reactor tank, it was deemed necessary to remove the lead nose, before safe access to the grid plate could be ensured for removal of the plate.

After removal of the graphite, most of the radiation in the thermal column was seen to be located in the central part of the lead nose, which contained integral thermocouples used for monitoring during reactor operation.

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[8] Memo of 5 October 2006, *Dose rate measurements through the B8 aperture and up from the reactor tank.*

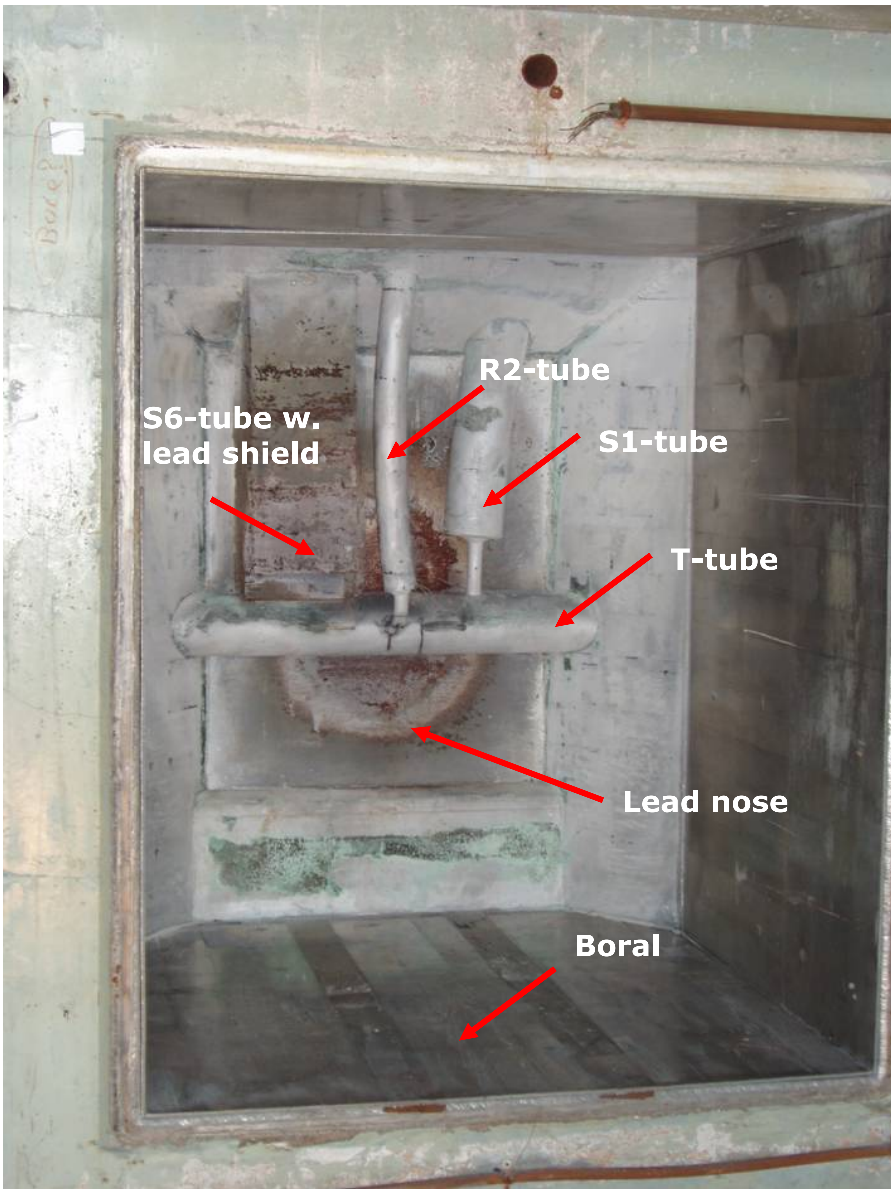

Figure 28. Thermal column with the graphite removed and an uncovered lead nose (R1-tube covered by S6).

It was decided to cut the thermal column immediately behind the lead nose. In connection with the detailed work plan for this assignment, drawings were thus prepared of cutting lines and hooking for lifting the lead nose.

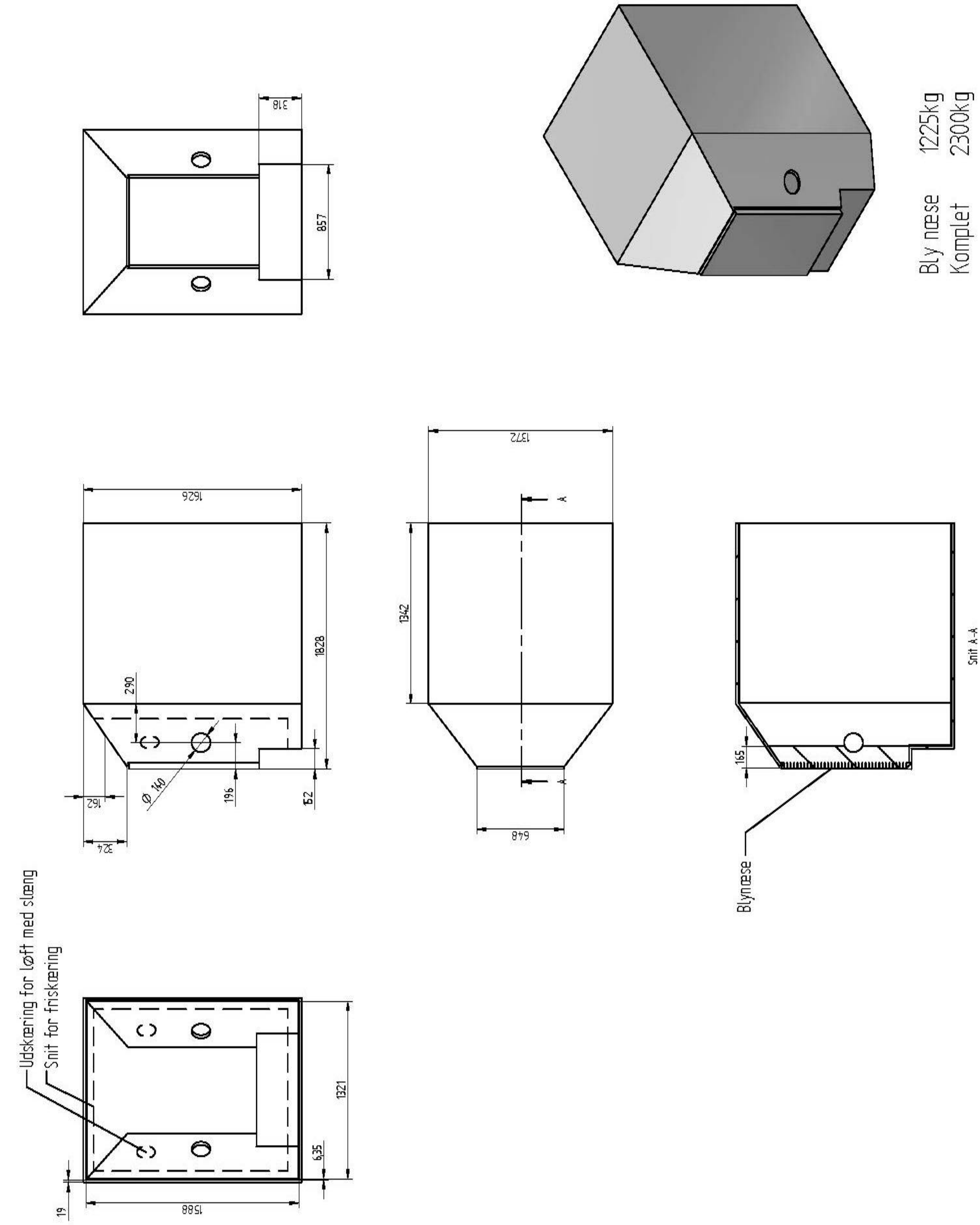

Figure 29. Drawing of thermal column with lead nose and cutting lines indicated.

After removal of the graphite, the structure of the thermal column made it possible to shield off most of the radiation by using standard 600×600×300 mm shielding blocks (heavy concrete). The blocks were positioned directly on an aluminium pallet. This would enable manual cutting of the lead nose if no tool could be found that was able to cut at a satisfactory speed.

According to accessible information from when the reactor was built, the thermal column consisted of 19 mm aluminium plates lined with 6 mm boral plates on the inside towards the graphite. The problem was to be able to cut through a structure that consisted of both "soft" material, such as aluminium, and the extremely "hard" boral plates with a total thickness of 25 mm. Consequently, a number of tests were made at first, using different cutting tools such as circular saws with different types of cutting discs and a plasma cutter. It should be mentioned that plasma cutting requires pressurised air at a minimum of six bar. This was available in the DR 2 building as basic equipment.

The different types of saw turned out to be inefficient and difficult to handle; in particular, they were not as fast as desired. The combination of hard and soft material made it difficult to find the right cutting disc with adjusted saw teeth. The plasma cutter, on the other hand, turned out to be the right solution. It could cut straight through the structure and was lightweight and easy to handle. Furthermore, it was easy to adapt it to be remote controlled.

Cutting of the lead nose from the thermal column was made by fitting the plasma cutter to a 2-metre extender. Cutting was performed by two DD technicians – one of whom performed the cutting using the extender, while the other handled the voltage switch from about 4 metres from the column. This was found to be the safest solution for reducing personnel doses, but was also used because the plasma cutter requires high voltage and works by means of electric contact (an electric arc of up to 20,000 volts) between the cutter head and the item to be cut.

Figure 30. Plasma cutting of lead nose. Shielding with concrete blocks at the centre; local air extraction used.

After the lead nose had been cut loose, it was taken by a crane straight into a DD steel container. The weight of the lead nose was 1225 kg. In the container, the lead nose was shielded with steel balls and other, less radioactive, waste.

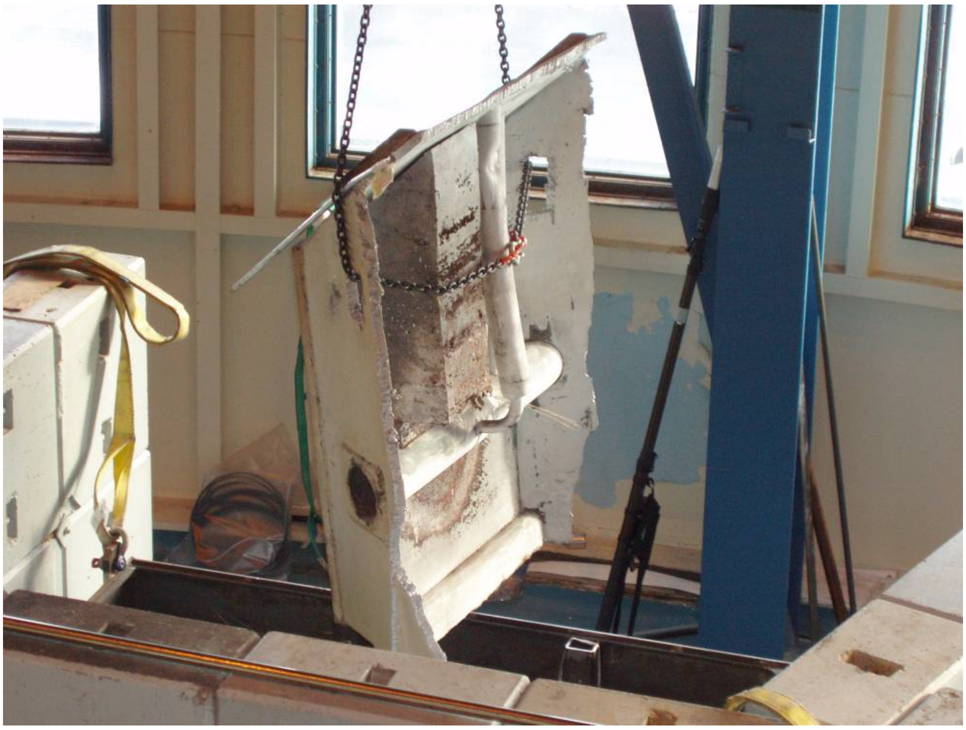

Figure 31. Lead nose cut off and placed in a container.

The conclusion was that plasma cutters for cutting and partitioning structures made of steel, aluminium and boral (in steel: up to 28 mm fine cutting and up to 40 mm coarse cutting) was advantageous for this type of assignment at DR 2; the process was as successful as expected and the plasma cutter worth purchasing. The plasma cutter can also be used for other projects. It has the following special advantages:

- fast cutting, also when cutting boral plates/composite structures;
- low weight;
- hand-held and easy to fit on an extender;
- remote control possible.

The use of plasma cutters requires the necessary electric voltage, pressurised air and the establishment of air extraction on the work site. Care must be taken because the work is performed at high voltage and temperatures. When the work was performed, local extraction was established at the cutting site and all employees present wore breathing masks with a particle filter (class P3), cf. figure 30. Another positive is that qualified smiths who are used to cutting metals can use the tool without any major difficulty, so the tool can easily be implemented in the tool assortment.

Consequently, the plasma cutter was used also to cut the grid plate and other remaining structures in the reactor tank.

One negative effect is that it is not possible to measure air contamination using iCAMs during plasma cutting, since the glass filters get clogged by fine dust particles. Monitoring was thus discontinued while cutting was being performed and resumed when plasma cutting ended. The work site was then cleaned. It must be noted that respiratory protective equipment was worn throughout the performance of the work.

5.2.4.4 Doses received when the thermal column was removed

The work of removing the thermal column consisted of two parts: removal of the graphite stack and removal of the lead nose. During the work of removing, recording and transferring the graphite stringers to containers, a total collective dose of 0.5 man-mSv was recorded. The lead nose was cut loose by means of a plasma cutter, which meant that the technicians were working relatively close to the radioactive item. The total collective dose was 472 man-μSv; two technicians received 200 μSv and 150 μSv, respectively, cf. chap. 9. The two performing technicians also received hand doses of up to 0.4 mSv, cf. chap. 9.

5.2.5 Removal of the grid plate

After removal of the lead nose from the thermal column, there was direct access to the grid plate and the remaining structures in the lower part of the reactor tank. The work involved was the following:

- removal of the grid plate from the reactor tank;
- removal of lead casings on instrument thimbles;
- removal of lining tubes from instrument thimbles; and
- removal of aluminium structures fitted to the bottom of the reactor tank (including a load-bearing structural rack for the grid plate and the rack for the lead nose).

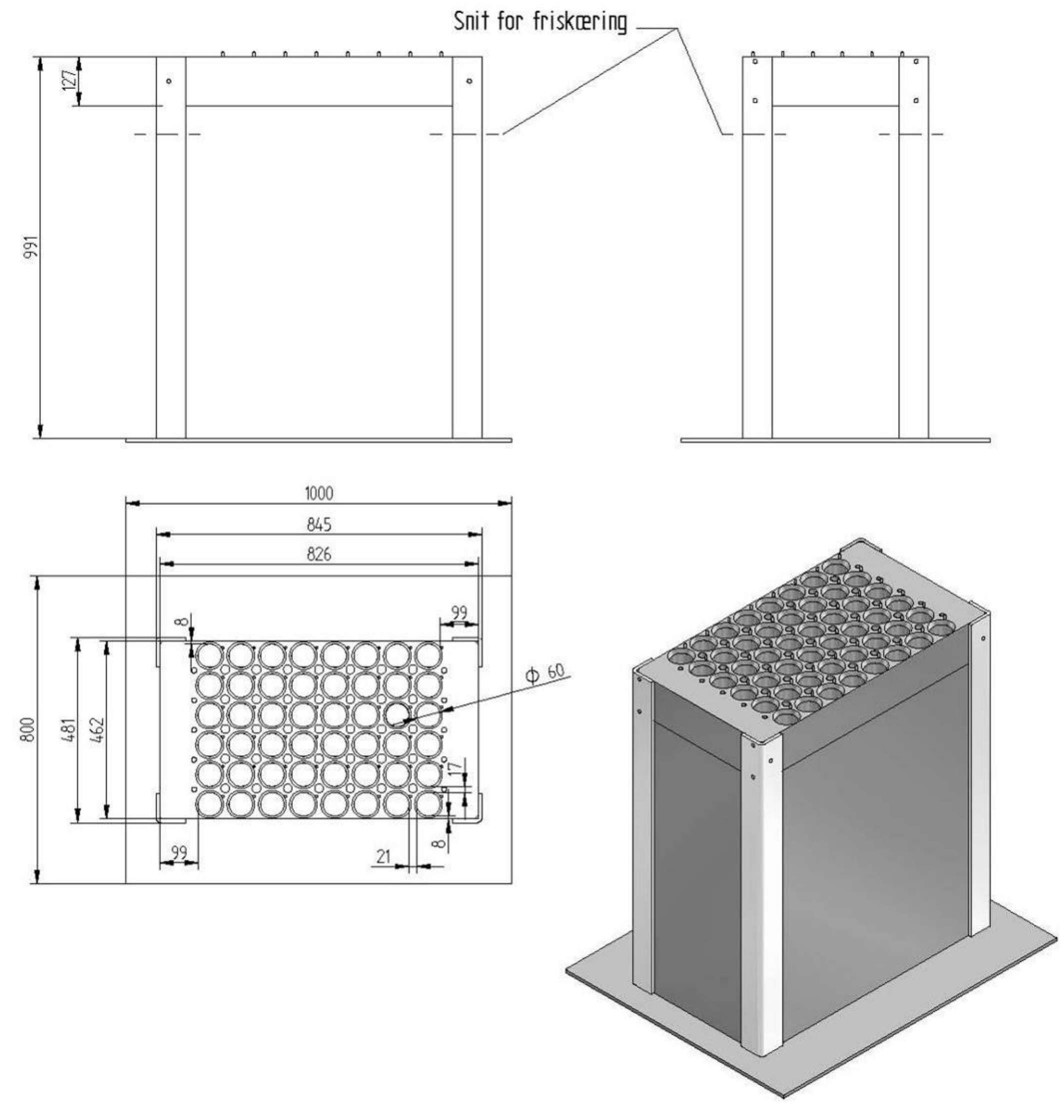

Figure 32. Grid plate with rack and cutting points indicated.

The grid plate was cut off from the reactor tank in the same way as the lead nose. Because of the high dose rate from the – now exposed – grid plate, an 8-metre extender was made to ensure that the grid plate could be cut from the tank aperture at the top of the reactor.

During the cutting and lifting of the grid plate, the hall area was temporarily classified as a 'red radiation area'.

Before the grid plate was cut free, a simple lifting bracket was made. The bracket was a 'once-only' tilting bracket fitted through the holes of the grid plate for the fuel elements. The lifting device was attached to the grid plate and tightened to ensure that the grid plate could not fall down when cut free.

Using the extender, the grid plate was cut off the rack at all four corners under the bolts with the plasma cutter. Then the crane lifted the grid plate out of the reactor tank via the chimney straight into a container.

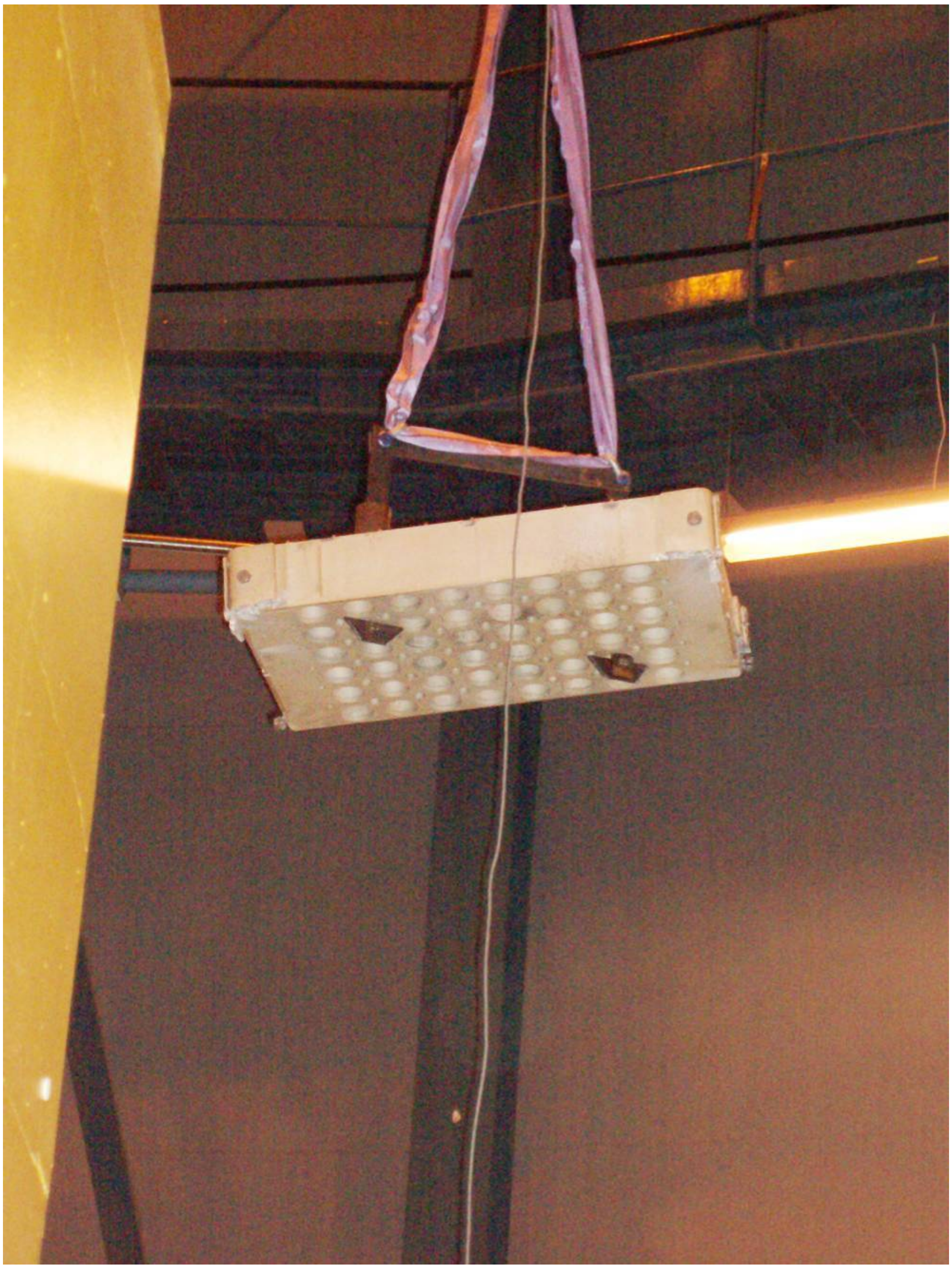

Figure 33. The grid plate being lifted out of the reactor tank. The lifting bracket and steel bolts at the corners are visible.

For optimum packing and shielding of the grid plate in a DD steel container, the container was first 'lined' with seven slightly radioactive plugs removed from the horizontal beam tubes. The plugs were placed at the bottom of the container. A layer of approx. 60 litres of 2–4 mm steel balls was placed over the plugs at the bottom of the container. The balls, which had previously been stored in the basement, had a self-levelling effect.

On top, a 40 mm steel plate was placed flatly at the centre of the container (coming from another partitioned item). A similar plate was made ready for use on top of the grid plate.

A steel box, approx. 20 cm high, was made also from 40 mm steel. The grid plate was placed in the box and the steel plate placed on top of this improvised shielding box. Another layer of steel balls was placed on top. The container was now in compliance with the surface dose rate requirements for being stored in the intermediate storage facility, cf. chapter 8.

Figure 34. The grid plate in the container before it was closed. The shielding box and plugs are barely visible at the bottom.

After removing the grid plate, the radiation level in the reactor tank was found to be down to 20 µSv/h,[9] so it was possible to perform the remaining work manually on site.

Figure 35. The remaining inside structure after removal of the grid plate. Lead covers on instrument thimbles have been removed.

After attaching the lifting brackets, it was possible to move the lead covers on the instrument thimbles straight to a container, while the remaining parts in the tank were cut free and partitioned using a plasma cutter and other hand-held tools. The work was carefully monitored by a health physics technician; as an additional check, all performing technicians wore wrist dosimeters during these operations. All persons wore respiratory protective equipment.

[9] Memo of 20 February 2007, *DR2 – dose rate measuring in reactor tank.*

Figure 36. The last internal parts of the reactor tank being removed.

The remaining part of the thermal column was removed when the concrete structure was demolished (described later in this report).

5.2.5.1 Doses received when the grid plate was removed

The grid plate was cut free by means of a plasma cutter with an extender; this allowed the operator to keep a distance to the grid plate when working. The grid plate was hoisted up through the reactor tank and straight into a shielded container. That is why the doses received by the two performing technicians were only 200 µSv each throughout the operation, cf. chap. 9.

5.3 Decommissioning of the cooling circuit in the basement

Decommissioning of the cooling circuit in the basement under the DR 2 reactor comprised the following items:

- decay tank (hold up tank),
- heat-exchangers, and
- pipes, pumps and ion exchanger units.

As the diagram in section 2.1.3 shows, the decay tank was physically located in a separate room in the experiment basement. The tank was thus removed as a separate activity. The other items were all located in the equipment basement. A number of pipes connected the individual elements in the two basement rooms with the reactor. All over the circuit, a brownish coating was more or less visible. Consequently, 29 smear tests/ drill tests were made at different locations in the primary cooling circuit. The samples showed that the coating contained up to 0.01 Bq/g material of ^{60}Co and ^{137}Cs, up to 100 Bq/g abrasion material in the form of ^{3}H and up to 600 Bq/g abrasion material in the form of ^{14}C. Concentrations varied several orders of magnitude in the circuit.[10] The following sections describe the removal and disposal of the cooling units.

5.3.1 Decay tank

During the operation of the reactor, the purpose of the decay tank was to delay the cooling water prior to entering the heat exchangers, to ensure that short-lived radionuclides, especially ^{16}N, had time to decay.

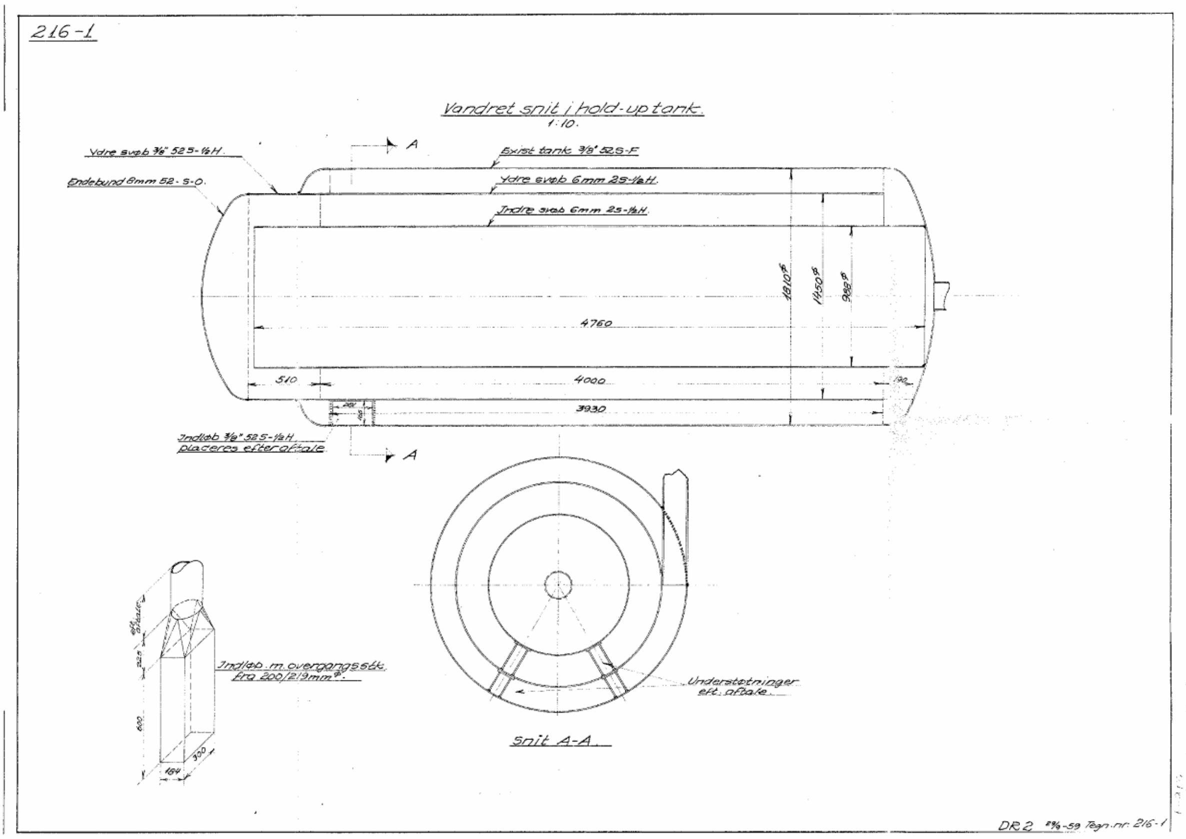

Figure 37. Decay tank, cross-section.

The tank was made of high-quality 8-mm thick aluminium with direct connection to the outlet at the bottom of the reactor tank. It was thus located directly underneath the reactor. The structure around the decay tank had concrete walls about one-metre thick, which also formed an integral part of the load-bearing reactor- and building structures.

The tank itself was approx. five metres long with an external diameter of approx. two metres. Inside, the tank had a casing (6 mm); water entry was from the bottom of the tank, while the discharge was via a horizontal outlet in the wall to the heat exchanger system in the equipment basement, cf. figure 38. The total weight of the tank was two tonnes.

Like the other primary cooling circuit items, cf. above, the tank was contaminated on the inside, primarily with ^{14}C and ^{137}Cs. It was thus decided to partition the tank and its casing into suitable sections that could be transported to DD's decontamination facility for decontamination with a view to clearance. The partitioning work was done with a plasma cutter.

[10] Memo of 5 July 2007, *Clearance measurements on components in the equipment basement of DR 2.*

The partitioned items were packed in DD's aluminium containers for internal transport.

All parts from the decay tank were decontaminated and then cleared for disposal as aluminium scrap.

5.3.2 Heat exchangers

The two heat exchangers located in the equipment basement (cf. figure 4, section 2.1.3) were six metres long and each contained 2,020 6 mm cooling pipes in almost their full length, corresponding to about 8 km of pipe. The tank itself was made of 8 mm thick high-quality aluminium. Inside, the tank space was divided by support plates to ensure an even distribution of the cooling water on the cooling pipes. The tanks had detachable external end plates made of 12 mm aluminium.

Being part of the primary cooling circuit, the heat exchanger tanks were contaminated inside. It was thus decided that the tanks would principally be partitioned and decontaminated in DD's decontamination cabin.

Figure 38. Heat exchangers in the equipment basement before removal.

At first, the heat exchanger end plates, which were bolted, were removed and sent to decontamination without much difficulty. The inside pipes, on the other hand, were not so easy to remove. 'Wear and tear' – surface erosion and deposits on the pipes meant that it was not possible to pull out the pipes completely through the tube plates. It was thus decided to partition the pipes before removal.

A number of minor trials were made with different cutting tools for partitioning the pipes. However, cutting and shearing with a hand-held cutting tool turned out to be impractical, since the pipe ends were deformed when cut, which meant that the pipes could not be pulled out.

Since wire-cutting of the concrete structure in the reactor hall was being carried out in parallel with the work in the equipment basement, it was decided to try dry wire-cutting on the pipes, cf. figure 39.

Figure 39. Set-up for dry wire-cutting of heat-exchanger pipes.

It was decided that the pipe ends would be cut on the inside of the tube plates. After the first trial cut, it turned out that wire-cutting resulted in no problems and went relatively quickly. It was thus decided that a total of four sectional cuts would be made with the wire-cutter to expose all pipe ends in the two tanks. It was easy to control the spreading of contaminated chips from the pipes by means of light plastic shield.

Figure 40. Pipe ends in heat exchanger after dry wire-cutting.

After the pipes had been cut (figure 40), they were pulled out of the tanks and further partitioned so they could be packed into DD's ISO containers for storage as radioactive waste in DD's intermediate storage facility. The outside casing of the tanks was partitioned, decontaminated and subsequently cleared for disposal as regular scrap.

It was decided that the pipes from the heat exchangers, which all had surface contamination, were not to be cleaned. This decision was made on the basis of trials with selected pipe sections, where manual cleaning and ultrasonic cleaning were tried. This turned out to be an inefficient and ineffective method in terms of resources, when compared with the fact that after partitioning and optimal packing all the pipes could fit into a single DD ISO container (~6 m^3).

A total of 2.7 tonnes (~50 %) of the total heat exchanger weight of 5.5 tonnes was cleared after decontamination of the outside end plates and the outside tank casings.

5.3.3 Pipes, pumps, ion exchanger units

5.3.3.1 Ion exchanger units

The ion exchanger system at DR 2 consisted of a cation exchanger and a mixed-bed ion exchanger (to the left in figure 41 below). The latter consisted of a mixture of cation exchanger mass and anion exchanger mass. During operation, these two types of ion exchanger masses were mixed by means of pressurised air. A number of pipes, pumps and various gauges made up the remainder of the system. A ceramic vessel for the chemical regeneration solution used in the process (sodium hydroxide and sulphuric acid were used) had previously been removed when DR 2 was closed down.

The cation exchanger was shielded by lead blocks, which were removed initially. Both tanks contained residue from ion exchanger mass and filter blocks, which were removed and control measurements were taken. The mass was seen to be slightly radioactive and was disposed of as radioactive waste.

Being part of the primary cooling circuit, the pipe system was contaminated on the inside, cf. page 49. Since pipe dimensions were small and the volume insignificant, it was decided to dispose of the pipe system as radioactive waste.

The ion exchanger tanks themselves were classified as contaminated with the option of being cleaned ("yellow waste") and passed on to DD's decontamination facility from where they were subsequently cleared as scrap iron.

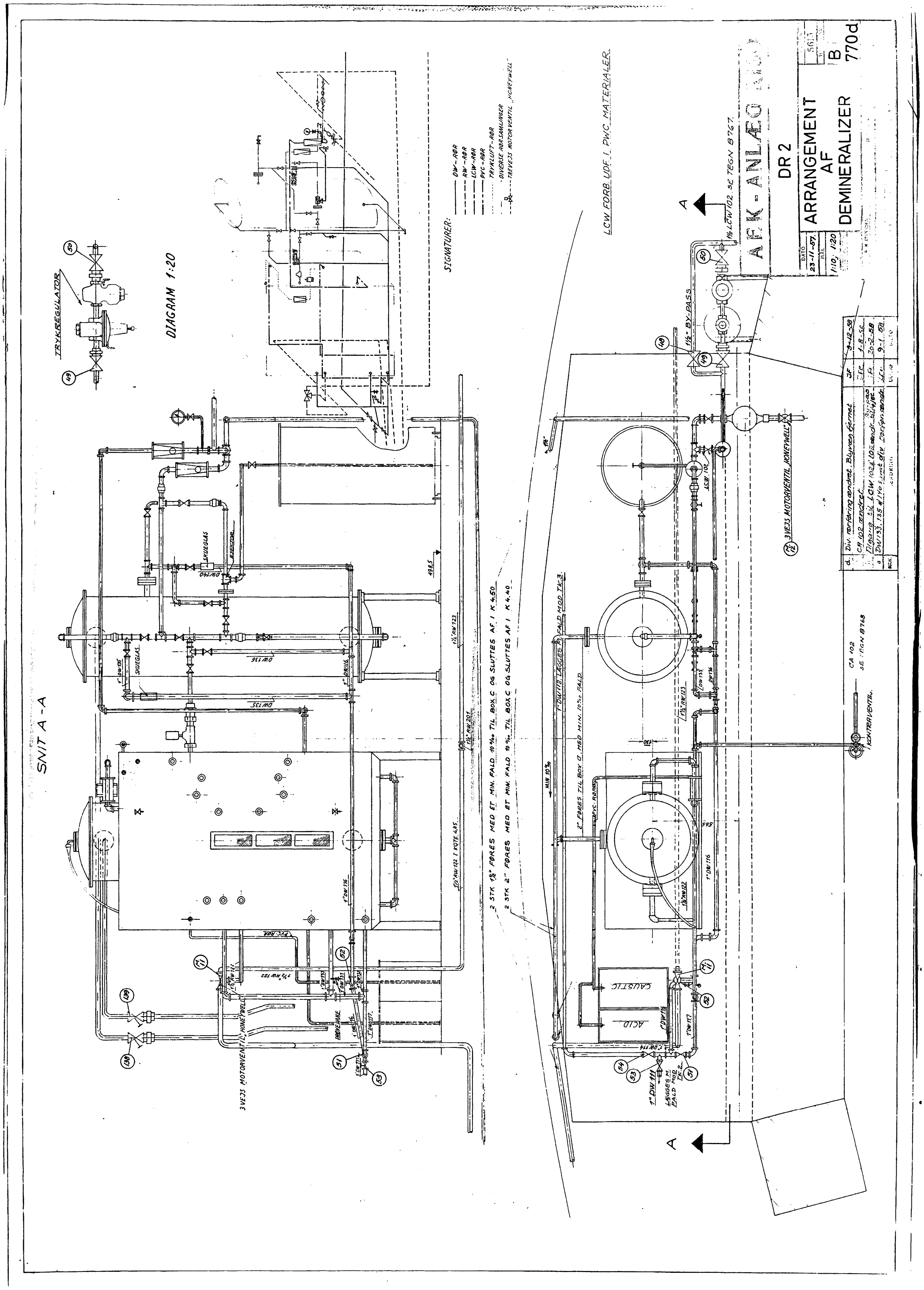

Figure 41. Ion exchanger, top view and cross-section.

5.3.3.2 Pipes and pumps in basement

As is apparent from the diagram in Figure 4 regarding the equipment basement in section 2.1.3, the cooling circuit contained a great many pipe connections and pumps, valves, gauges, etc. The main pipe systems from the hold-up tank to the heat exchanger were made of ø 6”-8”, aluminium pipes with a wall thickness of 6mm.

The system had three main pumps of US origin. These pumps were removed separately and destroyed in a process monitored by inspectors from IAEA and EURATOM.

The pipe system was seen to be contaminated on the inside, cf. page 49. All pipe sections down to ø 2” were partitioned into sections of one metre; they were then recorded and packed and passed on to DD’s decontamination facility. All other items were subject to control measurements on the site; items that could not be cleared were defined as radioactive waste and disposed of. All items that could be cleared on the site were disposed of as regular scrap.

The equipment basement also contained a sump with connection to the stand-by tank facility. The sump was made of steel and was cut out of the concrete floor and passed on for decontamination.

Pipes led through walls to the decay tank or the experiment basement were also removed. However, this did not include the return pipe to the reactor tank, which sits in the wall between the equipment basement and the experiment basement. The curvature of this pipe means that it can only be removed when the wall is demolished.

5.3.4 Removal of loose items stored at DR 2

Over the years, various items have been stored in both the equipment basement and the experiment basement. These items came from various experiments or from the operation of DR 2, the activities in the building after DR 2’s shutdown, as well as items from the other reactors on the site. Before the decommissioning of the cooling systems was launched, these items had to be removed. All items thus had to be logged in ADS, just as control measurements had to be taken and the items had to be disposed of in accordance with the same guidelines as those applying to the reactor unit.

The following table over work plans (as done) for selected items will help explain the scope of this work and the measures taken in regard to the individual items.

<table>
<tr><th>Photo</th><th>Description and action:</th></tr>
<tr><td>

1

2

3

4
</td><td>
Item:

Active ventilation system for reactor block incl. pipes, filters, motor, etc.
2 pieces of wood 6 x 14 cm, length approx. 8 m.

Measuring on site/in Clearance lab.:

Measured and interior smear tests taken showing contamination of all parts. The parts must be decontaminated in the cabin, which requires partitioning.
Pipes (photos 1+2) wrapped in plastic for transport.
Pipes transported to the hall for partitioning.
Pipes partitioned with a saw (in the hall) to max. 1 metre; packed individually in plastic and placed in aluminium container.
Pipes transported to the buffer storage facility for subsequent decontamination. >“YELLOW”.
Filter box (photo 4) lifted out for easier access.
From the filter box, the filters must be removed for depositing. Note these are absolute filters and oil residue may have to be collected upon opening. Packed and transported in ISO-container >“RED”.
Filter box (further separation if required) placed and transported in aluminium container to the buffer storage facility for subsequent decontamination > “YELLOW”.
Motor (photo 1) measured on site and disposed of as red waste to repository. Packed and transported in ISO-container >“RED”.
Pump for pneumatic dispatch and flow meter (photo 3) measured on site and removed to the repository. Packed and transported in ISO-container >“RED”.
Wood (photo 1) measured on site and disposed of in accordance with AHF instructions.
All parts are weighed.
Lifting gear and cutting tools will be required.
Initially, a work area will be established for partitioning pipes and separating the filter box. This area will have plastic sheet flooring and suspended plastic “walls” so as to avoid the spreading of contaminated fragments when partitioning.
Possibly, a ‘measuring area’ will be established in accordance with AHF instructions.

</td></tr>
</table>

Photo	Description and action:
 5	**Item:** • Parts from reactor DR 2 removed in the characterisation project. **Measuring on site:** • The box is moved to the hall and all items are measured and recorded in ADS >"**BLUE**". • Partitioned by means of a saw if transport in aluminium containers to the Clearance lab is required. • All parts are weighed.
 6	**Item:** • Box of old electrical components. **Measuring on site:** • Initially, the box is measured on site. • The box is moved to the hall and items are subject to control measurements; assessed for possible additional measurements in the Clearance lab => "**BLUE**". • The box is weighed.
 7	**Item:** • Neutron source shielding. Not from DR 2 **Measuring on site / in the Clearance lab:** • Transported to the AH-hall for separation and measurements. • Weighed.
 8	**Item:** • Dummy elements and other items from DR 2, saved but not used. • To be given to a museum. **Measuring on site / in the Clearance lab:** • All elements are measured on site. • Cleaned (surface) and packed in box ("museum box") (if they qualify for clearance). • Transported to a museum.
 9	**Item:** • Plastic container marked "chemistry". Has not been used in the operation of DR 2. Believed to come from a subsequent uranium project. **Measuring on site/in the Clearance lab:** • Containers measured on site; photo recorded. • Must be checked for residue/liquids in containers.

Photo	Description and action:
 10  11	**Item:** • Seven pumps. • Strong rubber hose ø10 mm, length approx. 45 m. **Measuring on site / in the Clearance lab:** • Pumps and hoses separated by cutting the hose at connecting point. • All items to be measured individually on site. • *If* measurement is 'positive', <u>pumps</u> with motors must be moved to the hall for measuring, checks and sorting; review of need for Clearance lab => "**BLUE**". • *If* measuring results are 'positive', <u>hoses</u> must be cut in suitable lengths (1 m) and placed in aluminium container for measuring in Clearance lab. => "**BLUE**". • It is also to be checked and decided if it would be best to separate pump and motor on site. • All parts are weighed.
 12  13	**Item:** • Misc. waste. Graphite/wood/metal. • The graphite is new graphite for use in the thermal column. • Misc. loose fittings, bolts, waste (paper, plastics, wood), etc., in the equipment basement. **Measuring on site / in the Clearance lab:** • Everything that can be measured 100 % on site is measured, while other items are packed individually for measuring in the Clearance lab. • If going to Clearance lab/ADS, these parts must be weighed.
 14	**Item:** • Graphite from DR 1-EXPO experiment. Has been exposed to neutrons. • 102 stringers in all, 10×10 cm, length from 1 m to 1.5 m. **Measuring on site / in Clearance lab:** • The stringers are not unpacked, but the plastic is wiped off lightly before being packed on a pallet; each stringer is measured on site. • A small material sample (e.g. a cut-off corner) is taken from each stringer and sent to NUK for measuring of ^{14}C. The samples are gathered in a plastic box for transport. • A test plan is agreed with NUK for quick clearance, possibly as an ongoing process with x samples per day.

Photo	Description and action:
	• Both graphite stringer and sample must be noted to fit together in pairs. • All parts are weighed. • Graphite stringers are stacked on an aluminium pallet without edging, wrapped in plastic all over the pallet and sent to the buffer storage facility. • Everything is logged in ADS, including the registration number of wrapping material on each stringer. • Graphite stringers are sent to the buffer storage facility in a container. The further process is determined on the basis of the measuring results from NUK.

5.4 Demolition of the biological shield / the reactor block

5.4.1 Determination of the extent of activated concrete: characterisation

A number of drilling tests were made and drill cores extracted to determine the amount and distribution of neutron-activated concrete in the concrete structure of the reactor shielding.

Generally speaking as regards the taking of drill cores, it was important to avoid contamination of the outermost "almost inactive" layer from the innermost "more active" layer, so through-going drilling was not to be made in one process. It was thus decided that it would be best to remove the first 100 cm of the core in a separate drilling process (outer part). The drilling head was then cleaned or replaced before the next 100 cm drill core (inner part) was taken. It had also been foreseen that if drill cores were to be taken with water as a coolant, the drilling fluid could contaminate the other part of the core, just as the water could result in leaching. In the drilling process it was thus necessary to monitor developments on an ongoing basis.

Initially, it was considered to take a drilling sample from the floor/floor deck underneath the reactor block. However, it was subsequently decided to let the active profile in the concrete continue down into the floor.

A total of 20 drill tests were made in the reactor block. All drilling samples were taken horizontally. In most of the drilling tests, drilling was done towards the vertical axis that goes through the reactor core. This generated a direct activity profile through the concrete layer. However, drill cores were also taken to determine the activity profile around the beam tubes and at the thermal column, as well as the igloo.

The positions of the 20 drilling samples and the results of the analyses of the drill cores taken are apparent from appendices 1, 6 and 7.

Based on the drill core examinations and analyses in DD's Clearance lab, it was determined that the non-clearable concrete (in the following called the "active profile") extended cylindrically from the core in a thickness of one metre in the concrete structure. Actually, it was a bit less, but for safety the profile was determined as stated. The height of the active cylinder was 2.5 metres from the floor with the same radius as mentioned above, 25 cm into the floor deck towards the basement. For practical reasons it was determined that the floor (deck thickness = 60 cm) underneath the reactor block was to be removed in its entirety. The defined activity profile is illustrated in figure 42.

Around the horizontal beam tubes, instrument thimbles and T-tubes, a higher degree of activation of the concrete was established close to and around the tubes. It was thus decided that a profile corresponding to the outer radius of the active tube + 10 cm was to be removed as radioactive waste.

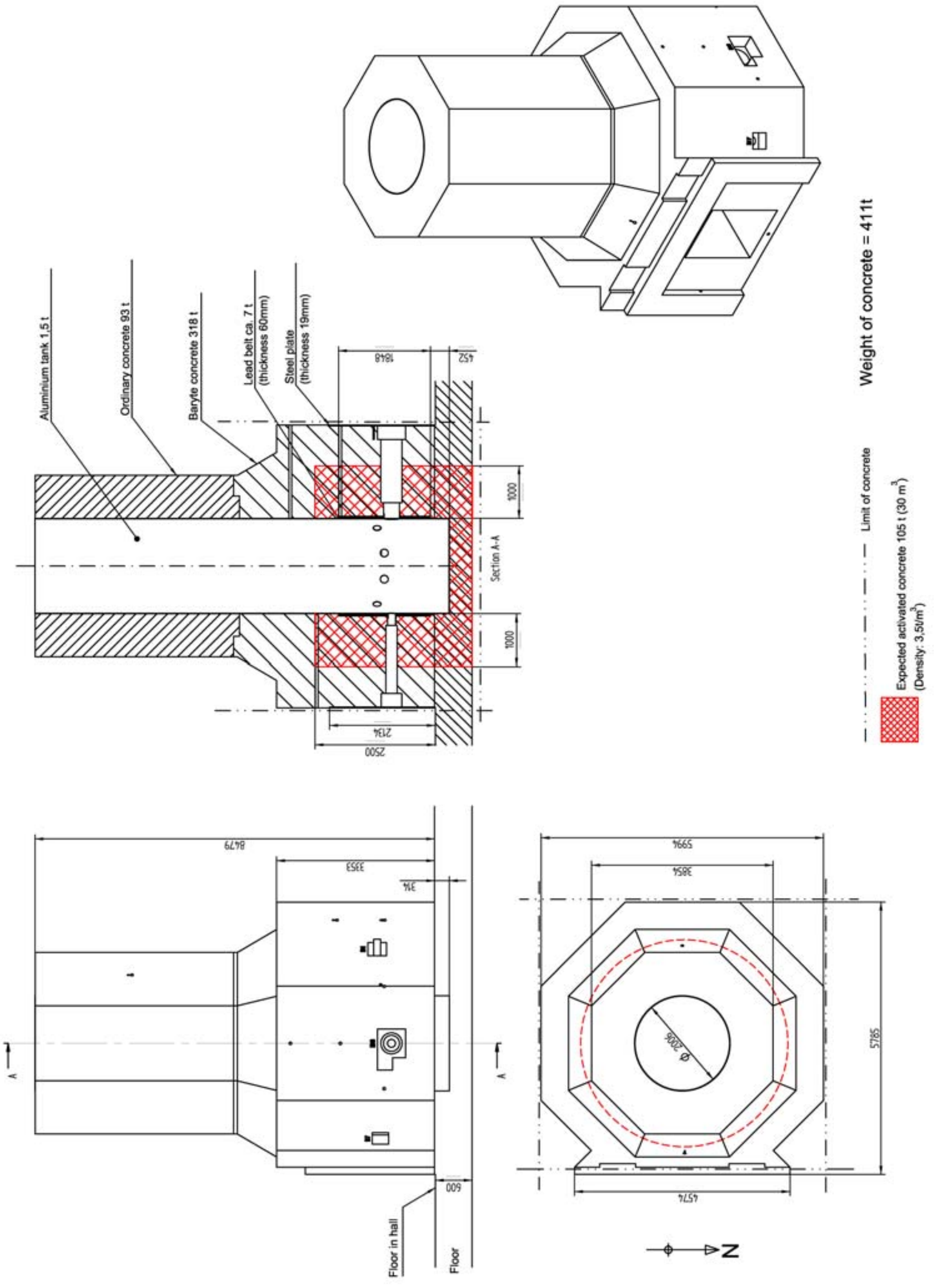

Figure 42. Active profile in the reactor block.

Based on the established geometry of the active concrete in the reactor block, guidelines could now be prepared for the demolition and partitioning of the concrete structure.

5.4.2 Demolition of the reactor block

Since DD does not possess the necessary expertise and equipment for demolishing major concrete structures, a public procurement procedure was held for the contract of demolishing the concrete shield. The procedure was carried out in the second half of 2006 and the concrete demolition contract commenced at the beginning of 2007. The expected contract period was about twelve months.

After prequalification, the four selected demolition companies were invited to submit tenders for the contract. The main requirements in regard to the tender and the contract were decided as follows:

- the tenderer must submit a proposal for a method (e.g. steel saw, wire cutter, hydraulic cleaving or hydraulic hammer)
- only dry methods are to be used (no water)[11]
- tents must be used and contamination may not be spread inside the building or to the surroundings (negative pressure)
- concrete and other materials from the reactor must be divided into active and non-active materials
- optimum filling of containers with active waste for the repository
- maximum safety and health protection
- full documentation and quality assurance.

This was further defined and specified in the tender documents for the tenderers. Being a state-owned company DD also specified that execution of the work was to be subject to the requirements of NMK96 [8].

5.4.2.1 <u>Requirements regarding the concrete demolition contract</u>

The demolition contract consisted primarily of concrete demolition work as well as the handling and disposal of demolished materials. The special aspect of this demolition contract was that parts of the structures were slightly radioactive, which meant that dust and any water used could involve a risk of harmful spreading of activated materials. This made high demands on the contractor’s planning, choice of methods and documentation.

The following demolition work was comprised by the contract:

- establishment and operation of a work site and the related welfare measures;
- demolition of the reactor block;
- establishment and operation of environmental measures in connection with the demolition work;

[11] Derived from “Lessons Learned” in the DR 1 project.

- disposal of clean (non-activated/non-contaminated) demolition products;
- handling of contaminated/activated demolition products that must stay on DD's premises.

The tender documents laid down two primary success criteria for the demolition of the reactor block:

- the spreading of dust, cutting fluids and other sources for the spreading of activated material must be avoided;
- the contractor's performance must at all times seek to minimise the waste that is to be deposited as radioactive waste.

Method

The contractor was given free reign to choose working methods and auxiliaries, but was asked to describe the planned methods, etc., in detail in the tender submitted.

However, the contractor's choice of method had to ensure that activated waste and waste for clearance were separated. Activated concrete thus had to be separated from non-activated concrete and partitioned into suitable sizes for handling and disposal. The selected method is described in section 5.4.2.3.

Water

A number of additional conditions for the work were laid down, including conditions for the use of water. The use of water in connection with the demolition of DR 2 was deemed undesirable, the reason being that water with radioactive concrete dust is a problematic material. For one thing, the concrete may contaminate the water, which would thus have to be cleaned, and, for another, the many ducts and pipes in the reactor block meant that water used for cutting, for instance, could be difficult to manage, causing a potential risk of water accumulating in places where it could be contaminated, after which it could flow out onto the floor of the reactor hall and/or down into the basement without being controlled. In the light of this, the use of water when processing the reactor block itself was not permitted.

Tent

The demolition work to be carried out was not allowed to contaminate the reactor hall. It was thus a requirement that walls and ceiling be protected against dust from the demolition process.

This was to be ensured by establishing a ventilated tent around the reactor block in which ventilation could be established with a negative pressure in relation to the surroundings, thus leading to dust being absorbed. This would maintain a good working environment without any spreading of radioactivity to the other parts of the DR 2 hall.

To give the contractor a suitable reference basis for preparing a draft solution and for pricing the assignment (submission of tender), the tent was specified as complying as a minimum with the requirements stated in "The green asbestos guidelines",[12] including the Danish Working Environment

[12] Common knowledge in the demolition and asbestos clearance industry

Authority's executive order no. 1502 of 21 December 2004. In addition, the contractor had to comply with the following requirements, among others, regarding the equipping and operation of the tent:

- establish a procedure – possibly by means of a lock – to ensure that dust could not spread when demolition products were transported out of the tent;
- organise the tent in such a way that a change of clothes occurred before people left the work area;
- establish separate ventilation of the tent, independent of existing hall ventilation;
- establish negative pressure in the tent. The negative pressure in the tent had to be monitored electronically. If the negative pressure disappeared, there was to be an automatic, distinct alarm with sound and yellow light, following which work had to be stopped, until the cause of the alarm had been found and remedial action taken;
- air replacement was to ensure that visibility in the tent did not prevent the work from being done safely and precisely;
- the air from the tent had to be filtered before discharge into the open space (the hall). The last filter in the extraction system had to be a HEPA filter as a minimum;
- it had to be possible to clean the tent itself effectively;
- it had to be possible to clean the extraction system effectively.

The final dimensions and layout of the tent were determined in cooperation with DD in the detailed design work and adapted to the selected method and the necessary work procedures in the demolition process and waste management process, as described below in more detail.

In addition, a number of requirements were stipulated regarding the handling and packing of DD's containers with active material, disposal of cleared waste as directed by the municipality, and regarding clearance and cleaning of work sites.

Following the public procedure, the concrete demolition contract was awarded to demolition contractor G. Tscherning A/S as the general contractor. The contractor's team consisted of G. Tscherning A/S (concrete demolition) in cooperation with MT Højgaard's drilling and cutting department (drilling and wire-cutting), the ventilation firm Dantherm Filtration (ventilation and central extraction), the scaffolding firm E-service (tent and scaffolding) and the haulage contractor K. Jensen & Sønner (waste disposal). In addition, a number of minor tasks were performed by external subcontractors (steel cutting, various items of equipment, etc.).

5.4.2.2 Preparation works, workplace layout

Tent

A tent was set up around the reactor block as part of the workplace construction. The tent was set up to be tightly sealed and with a strength that enabled the establishment of a negative pressure and movable local extraction points. The size of the tent was 15 x 14 m, its height 10 m. The construction was comprised of scaffolding material (steel) in 70 cm width, covered on the inside by strong, transparent tarpaulin to have the highest possible light incidence ('Monarflex'). The bottom 1.5 m was clad on the inside with plywood to keep machines, tools or waste from perforating the tarpaulin (the tent cloth). The inside of the tent was thus smooth, tight and easy to clean.

The roof of the tent was made up of lattice girders to which plywood sheets were attached. This made it possible to carry out inspection, or make changes or repairs. The sealing between roof and tent sides was ensured by the use of sealing strips.

Figure 43. Scaffolding built up around the reactor.

To optimise the work site area and ensure smooth handling of waste materials to be transported from the premises, the existing side-hung door for the reactor door was replaced by a modern, vertically operated, articulated lifting door (vertical rolling with rail guides on the sides). A lock was established between the tent and the gate in the hall; the lock was built up like the tent itself. An articulated lifting door was installed between the work site at the reactor block and the reactor hall gate. The lock enabled the necessary performance of cleaning and control measurements on water and material outside the work site around the reactor block. Subsequently, cleared waste and material were removed via the hall gate. Doors were established in the lock as access paths, but only for DD's health physics staff and supervisory staff.

The work site layout in the reactor hall is illustrated in figure 44.

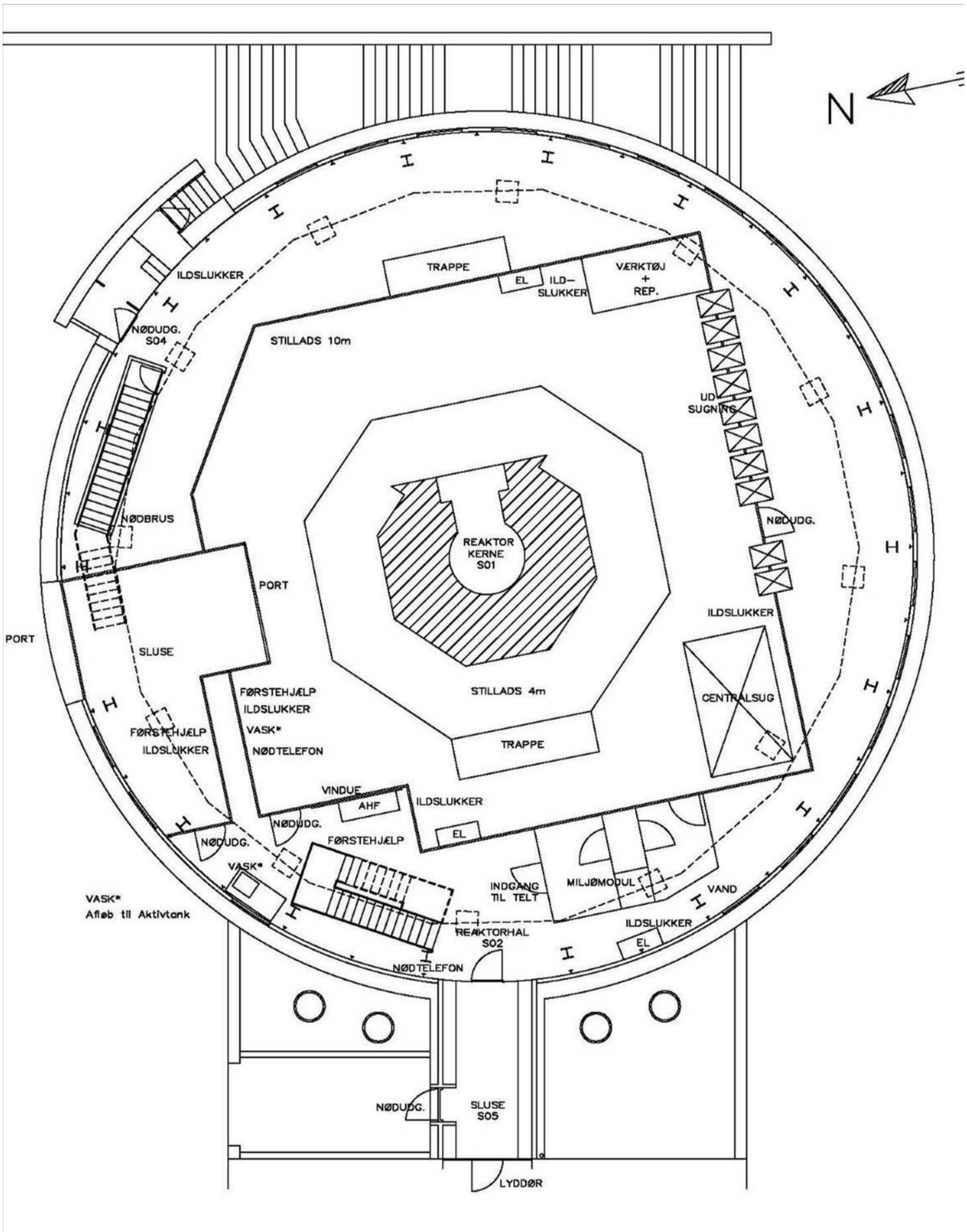

Figure 44. Layout plan for tent in concrete demolition (process step 1).

All joints in the covering tarpaulin of the tent were made with vulcanized, two-face adhesive joints. Furthermore, a number of escape doors were established in the tent. This also gave DD's employees quick access for inspection of the work site.

Figure 45. Scaffolding covered with tarpaulin on the inside; three-section person lock being built.

Normal access for the contractor's staff to the work site was via a three-section person lock that was established. Changing facilities and lock access were outside the tent with direct access from the hall and from the tent. The lock building consisted of an area for removing any contaminated work clothes, a passage and an emergency shower, as well as an area for getting into clean clothes or a coat. Demolition work and the stay in the tent for this work were carried out by personnel wearing coveralls and turbo masks with a minimum of P3 filters.

Passage between the reactor hall and the work site was via the lock module. Passage in and out of the hall was via DD's existing units and facilities. When someone left the hall and the work site, a control measurement was taken on a stationary hand and foot monitor. All personnel at the work site wore TL dosimeters and electronic MGP dosimeters (cf. chapter 9.1).

During the contractor's work period, daily checks were made of the tent cloth and structure to reduce the risk of leaks.

The tent solution chosen offered great structural strength in addition to the necessary sealing, optimum light incidence, option of visual inspection of the work from the hall, good options for attaching supplies and auxiliary materials, just as the tent structure made it easy to clean the surfaces on the inside and to inspect and possibly repair the tent from the outside.

For the first part of concrete demolition, which was to be carried out by small-sized machines, a steel scaffolding work platform was established at a height of 4.5 m around the chimney. The platform was about two metres wide and was attached to the reactor block to withstand the horizontal forces when the demolition machine was in operation. To keep debris from falling to the bottom of the reactor tank, a cover was established inside the chimney about four metres above the floor, just over the upper edge of the lower part of the reactor block. This cover was in the form of a round five mm steel plate, resting horizontally on the fuel rack on the side of the tank (cf. figure 16).

The room underneath the reactor tank (the hold-up tank room) was separated from the other parts of the basement by establishing a tight, temporary wall with a door, covered with the same type of tarpaulin that was used for the tent. To maintain negative pressure in this room, a separate extraction unit was installed ("environmental box") with a HEPA filter and discharge into the basement.

Ventilation and local extraction

Ventilation in the tent was established to reach a general negative pressure (compared with the hall) and for connection of localised extraction units to be used at demolition tools. Both units were gathered in environmental boxes (independent, filtrating ventilation units, such as those used in asbestos work, etc.). The environmental boxes featured a coarse filter (pre-filter), a fine filter and a HEPA filter.

All air from the tent ventilation system was discharged straight to the hall, which meant that air discharged from the work site was covered by DD's ongoing air monitoring, cf. chapter 9.

A general negative pressure, which was maintained in any event throughout the performance of demolition work, was established by setting up eight environmental boxes. The air renewal during demolition of the reactor block was calculated to correspond to the air renewal for asbestos work, 10 times per hour. The environmental boxes were placed on the southern side of the tent (cf. figure 44), as the negative pressure was established by extracting air just above floor level. For the purpose of ensuring that the negative pressure was always maintained at 20 Pa in relation to the hall, the environmental boxes were connected to two separate power supplies. The adequacy of the negative pressure was monitored continuously with pressure meters; any decline to a critical level triggered both a visual and a sound alarm, and also triggered the sending of a text message to a pre-designated mobile phone.

The local extraction system was made in the form of a central system. Via a pipe system with 10 closable outlets/connectors, the system was placed along the side of the tent at a location where hoses for local extraction could be connected. This reduced the number of extraction hoses directly on the floor. Typically, 5–6 local extraction points were used at a time. In the case of mechanical demolition (e.g. a demolition robot), the local extraction point was attached directly to the demolition tool, while in the case of wire-cutting work, which was carried out in cutting boxes, the local extraction point was attached to these boxes.

The system established reduced the emission and spreading of dust inside the tent itself, since cutting dust and minor concrete fragments were collected close to the source and put directly into drums for further processing.

The solution chosen also helped to ensure that when the filters were removed at the end of the process, the central extraction system was easy to clean.

The chosen ventilation solution was assessed to have contributed to a high level of assurance against breakdown and to flexible adjustment of air change, to orderly access to local extraction in all work areas, to the collection of dust close to source, to safe handling of collected dust volumes and to an alarm system if the negative pressure in the tent failed. The ventilation system and the central extraction system thus lived up to the owner's requirements for work performance.

Figure 46. Left photo: extraction system on the discharge side; at the back discharge from a local extraction point. Right photo: system for local extraction with a drum for collecting dust; discharge via HEPA filter.

The level of contamination in the tent was assessed daily through sampling checks made by DD's health physics staff, cf. chapter 9.

Occupational safety and health

The OSH measures were also given high priority in the concrete demolition project as described in more detail in section 5.4.3.

As a starting point it was decided to lay down requirements as to safety and the use of personal protective equipment (PPEs); these requirements would apply to all employees at the work site (in the tent) and these rules would apply throughout the project period, until the site had been assigned a lower classification.

Requirements were made as to the use of traditional PPEs, such as hardhat, safety shoes and eye protectors. Requirements were laid down as to the use of respiratory protective equipment with particle filters. In case of more long-term (work-performing) stays in the tent, "turbo" masks had to be used, while for a short stay (e.g. for taking control measurements) disposable masks could be used. All filters/masks had to be class P3, which protects against most types of harmful dust (e.g. quartz dust, asbestos dust, etc.), as well as aerosols, also covering radioactive particles.

Figure 47. OSH was essential in the project.

As regards work clothes, it was required to wear coveralls for long (work-performing) stays in the tent. For short stays, DD’s normal coat could be worn. For the performance of work gloves had to be worn.

All scaffolding and rails established were approved through inspection before use and the statutory signs were put up. For work high up on the reactor block, safety lines were used.

Since concrete demolition is a noisy affair, a visual alarm system for fires, etc., was established for safety reasons. Furthermore, all contractor staff carried radio-controlled communication equipment.

The tent was fitted with windows that allowed inspection of the work site from outside; furthermore, a number of emergency exits had been established and fire-fighting equipment, bandage box and eye wash station were set up. An emergency shower was established in the person lock.

Before the work started, all external employees at the site received instructions in how to work in classified areas and they received DD's safety folder. Around 50 external employees received these instructions. All external employees were fitted with a TL dosimeter and wore electronic dosimeters. In addition, they participated in DD's urine sampling programme.

5.4.2.3 Work schedule for the demolition of concrete structures

Method chosen

After the contractor had been selected and the contract had been signed, the following method for demolition and tools was agreed:

- demolition of concrete using a hydraulic hammer fitted to a "Brokk" demolition robot – remote-controlled;
- dry wire-cutting, remote-controlled, e.g. for cutting horizontal beam tubes (concrete, steel, aluminium, lead).

Demolition of other materials by means of:

- a plasma cutter (steel, aluminium);
- saw, hand-held (aluminium tank);
- blowtorch (steel, pipes).

The work plan for demolishing the reactor block consisted of a total of seven process steps:

1) establishment of the work site;
2) demolition of non-activated superstructure (chimney);
3) demolition of non-activated material from reactor block, upper part;
4) removal of activated concrete around beam tubes;
5) demolition of non-activated material from reactor block, lower part;
6) demolition of activated material from reactor block;
7) removal of activated concrete from floor.

Process step 1, Establishment of the work site, is described above (5.4.2.2). The basic work site layout is shown in figure 48.

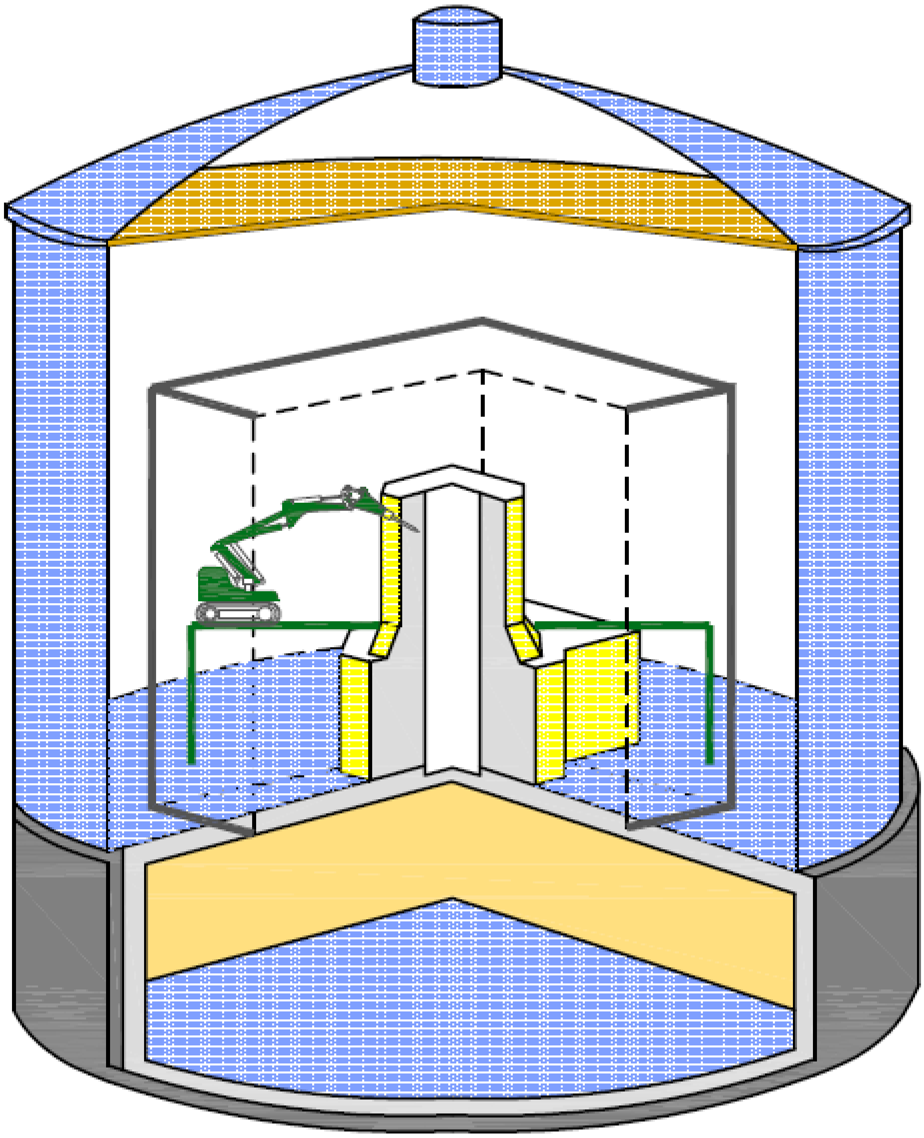

Figure 48. Basic work site layout for concrete demolition.

The individual process steps in the demolition of the concrete structure are shown in figure 49 and are described in more detail in the following.

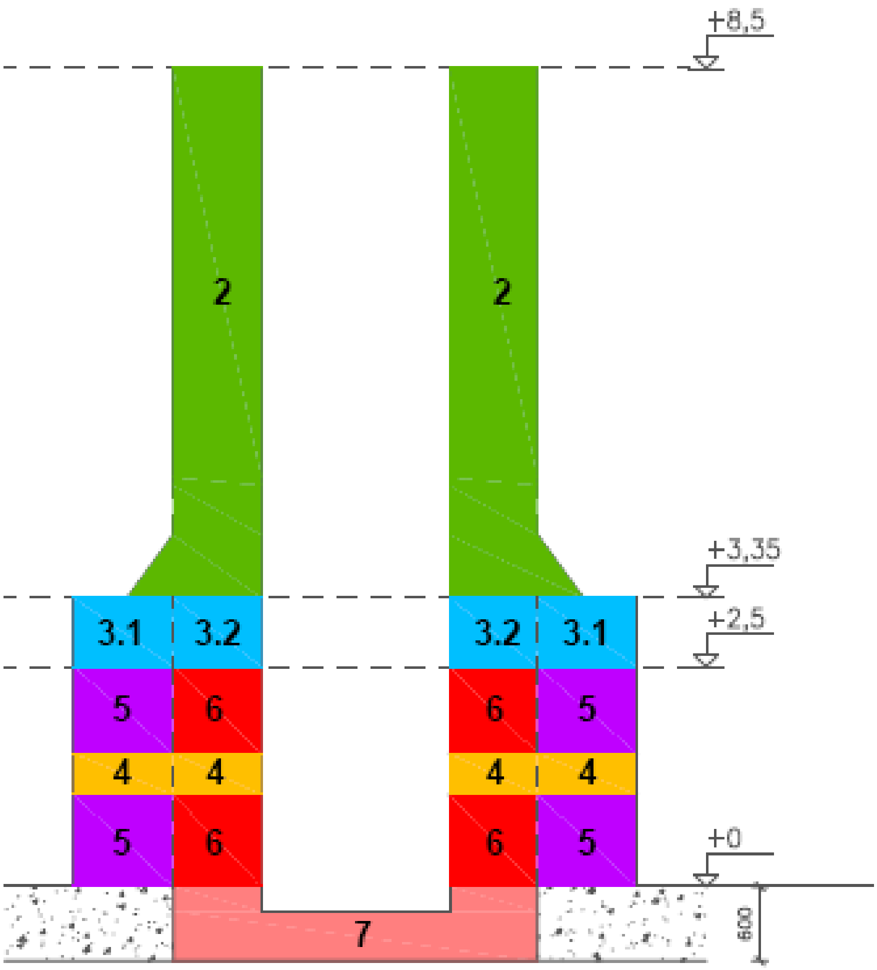

Figure 49. Concrete demolition, process steps 2–7.

Figure 50. Remote-controlled demolition robots of the 'Brokk' type; these were used for the assignment.

Process step 2, Demolition of non-activated superstructure (chimney)

In connection with the establishment of the work site, a work platform was established for demolition work using a remote-controlled mini-machine (Brokk 90), placed at a height of 4.5 m around the chimney stack. Local extraction was established on the machine and the platform and in the chimney. All subsequent break-up work during the contract was performed with connected localised extraction in the work area.

To keep debris from falling to the bottom of the reactor tank, a cover was established inside the chimney about 4 m above the floor, just over the upper edge of the lower part of the reactor block.

The chimney, from elevation level +8.5 m to + 3.5 m (both approximate elevation levels in relation to floor) was demolished by being broken up using a hydraulic hammer on a mini-machine. The concrete was basically estimated to have a strength of 40–45 MPa, which made this type of break-up work possible.

The demolition robot was used to demolish the concrete down to the *shoulder* of the reactor block at a height of about 3.5 m. The aluminium tank was loosened and removed continually during break-up work. Reinforcement bars and pipe sections were also removed continually during break-up work.

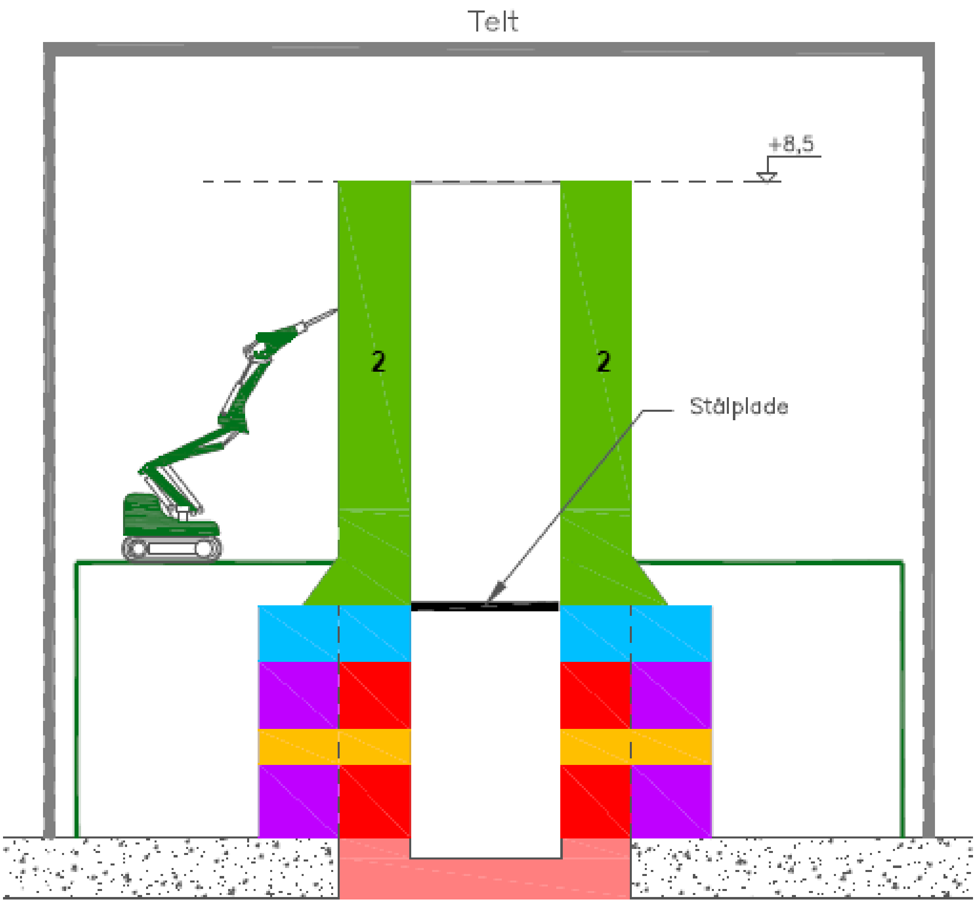

Figure 51. Process step 2, demolition of non-activated superstructure (chimney).

Figure 52. Demolition of chimney from platform. Remote-controlled demolition robot 'Brokk90' in action.

Figure 53. Chimney broken up; platform is removed; reactor tank awaits cutting up.

Process step 3, Demolition of non-activated material from reactor block, upper part

Initially, the existing circumference of the reactor block was measured by a surveyor to determine the benchmarks for removing concrete and for ensuring separation between clearable and non-clearable materials, cf. DD's performance requirements.

For visual recording of progress and in order to see the dividing line during execution, a number of horizontal holes were drilled from the reactor face. These holes were drilled until just in front of the dividing line towards active concrete, which made it possible to cut off material without ongoing control measurements from a surveyor.

The work platform was lowered to a height of two metres above the floor for breaking up the exterior concrete.

The upper, outside, non-active concrete was broken up using a hydraulic hammer on a mini-machine controlled from the platform.

During break-up work, reinforcement bars and pipes were removed on an ongoing basis. The external steel plate was cut off continually.

Concrete and pipes, etc., were handled as "white waste", i.e. cleared material. These materials were checked by AHF before being driven out through the lock for further processing and were deposited in accordance with municipal instructions.

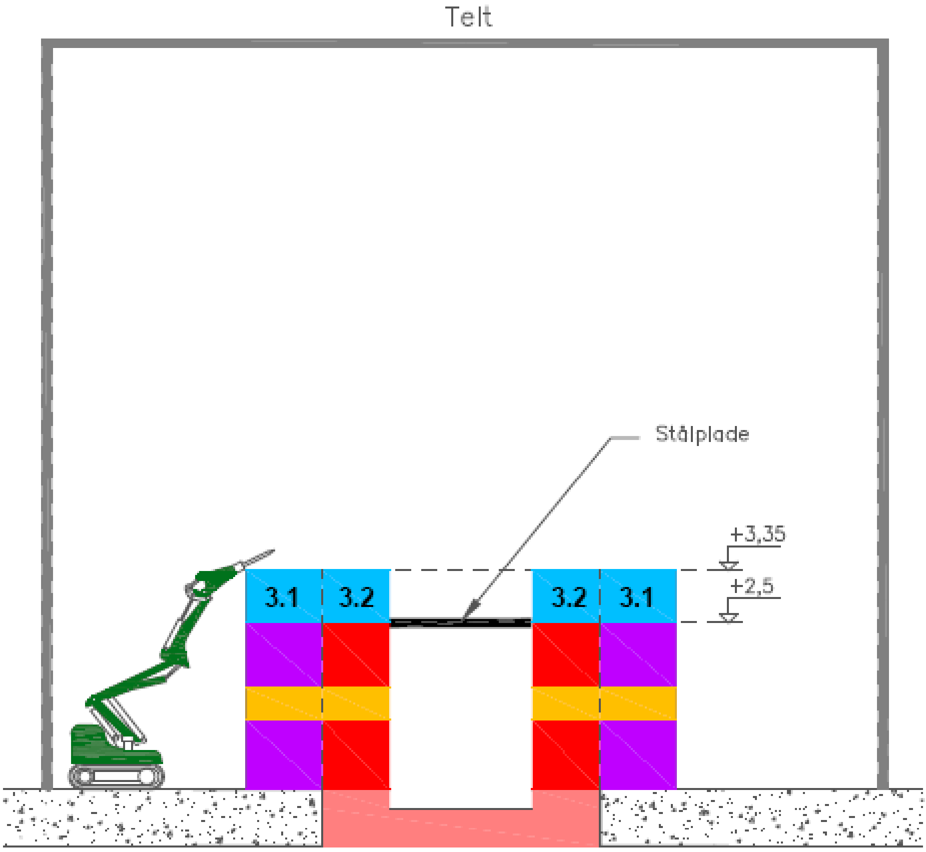

Figure 54. Process step 3, Demolition of non-activated material from the reactor block, upper part (down to elevation level +2.5).

Figure 55. Demolition of upper part. Demolition robot 'Brokk330' remote-controlled from the lift.

Figure 56. Upper part of the reactor block broken up and preparations for cutting down the reactor tank.

Process step 4, Removal of activated concrete around beam tubes

Initial test cuts

The design of the reactor block had a vertical, layered structure consisting of external concrete (baryte concrete), a lead belt cast in aluminium, and an inside aluminium tank (cf. figure 42). This was thus a combined (sandwich) structure consisting of soft and hard materials. Also, it was clear that cutting had to be done from outside the reactor. The wire for cutting thus had to be inserted in the tank and taken back out to the wire-cutting machine. The first cut would thus be in the soft part of the inside aluminium tank, then moving on to the lead belt around the tank, before the wire could reach the concrete.

Since there was no previous experience with cutting using wire in this type of concrete structure, neither by DD nor in the experience of the contractor, it was decided to make a test cut.

A test structure was established consisting of concrete, aluminium and lead blocks, i.e. an approximation to the structure at hand.

Figure 57. Test structure set-up for a test cutting using wire.

Several test cuts were made to determine the right type of wire. A type of wire that could be used was identified, but it was clear that because of the elasticity of the lead and the melting that would occur because of the heat from the wire, the first part of the cut was going to be the most difficult to manage. The conclusion was that in order to ensure that the defined active profile of the concrete around the beam tubes was cut off, any displacements would have to be taken into account when placing the wire.

Figure 58. Example of cutting lead using a wire.

Wire-cutting

The ten tube ducts in the concrete structure were cut out by means of wire-cutting without using water for direct cooling of the wire.

In preparation, four small holes Ø 50/35 mm were drilled two metres through the concrete wall and the lead/aluminium tank. The cast-in iron plate on the outside of the reactor block was used for attaching the drill. A magnet drill was used to drill a hole and cut threading in the iron plate for attaching the diamond drill. To avoid damaging the diamond drill, a hole (Ø 60 mm) was first cut in the iron plate, following which the diamond drill could be pushed through and into the concrete.

A special PCD diamond drill was used for dry drilling with pressurised air on the drill, which means that the air was pushed through the drill past the segments that cut the concrete. Externally around the drill, a guide was fitted with a suction hose from the central extraction system in order to collect the dust.

Wire-cutting was then performed between these holes, so the individual tube was cut out in a square profile in the form of a concrete block that could be removed from the wall.

The wire cutter was fitted on a movable concrete foundation block on the floor of the reactor hall. This ensured the stability of the wire cutter during work. The wire was pulled through one of the diamond-drilled holes in the reactor block into the tank, from where the wire was led to the next hole and back out. In this connection the health physicist decided that the time contractor employees were allowed to stay in the reactor tank had to be minimal. After the wire was retracted, it was gathered in a box with brushes and extraction was used to collect dust that the wire ran through during cutting. Furthermore, in the reactor tank a central extraction system was established from three points used for collecting dust from the wire-cutting.

To protect personnel in the hall against contact with the wire during cutting, a plate screen was put up in front of the place where the diamond wire went through open air. The wire-cutting process was remote-controlled.

Figure 59. Cutting of horizontal tubes using wire.

When the ‘block’ had been cut loose on all sides, it was placed on two flat bars at the bottom of the recess. These flat bars were used to transport the block out of the reactor block.

During cutting with the wire cutter it was necessary to use approx. 1 m^3 of water for cooling the electric motor on the wire cutter. The water did not come in contact with the concrete, but was recirculated in a closed system from the container through the pump to the electric motor and back to the tank. A water suction device was available in the hall for removing water in case water spilled out.

When the work was over, all tools and gear used for breaking up, drilling and wire-cutting of the concrete were removed but not until a control measurement had been made using either a contamination monitor or a gamma spectrometer.

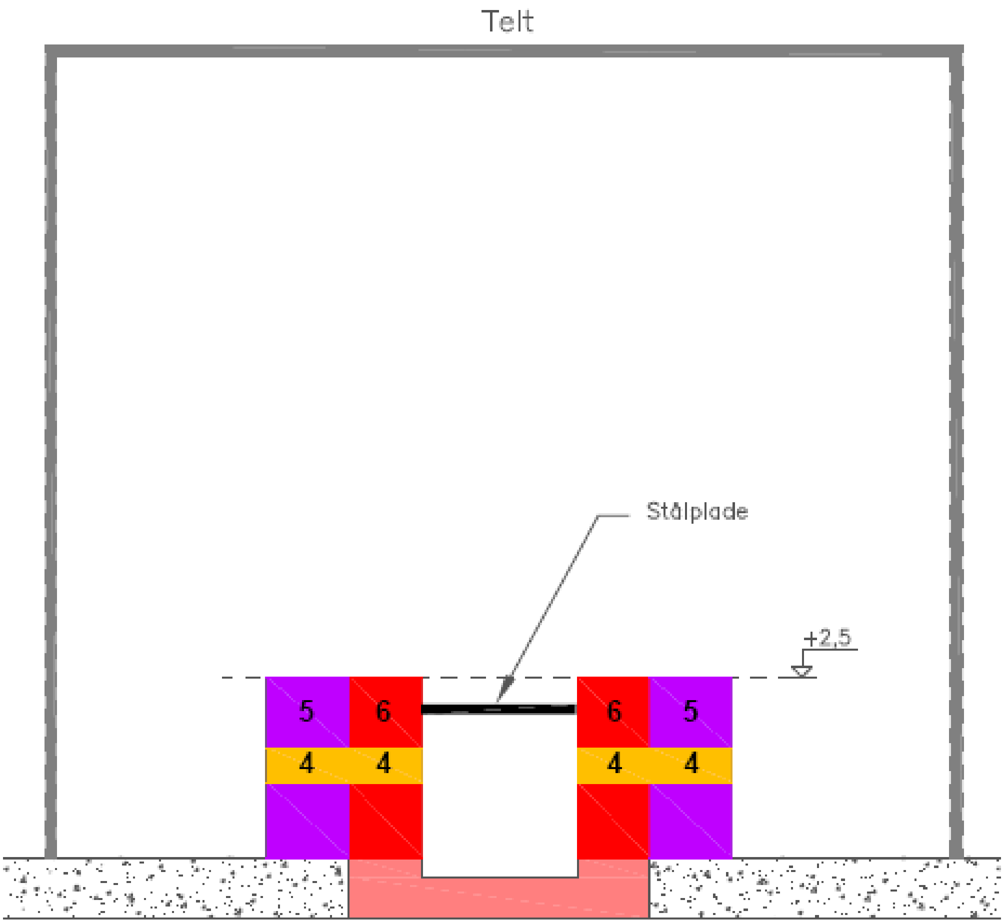

Figure 60. Process step 4, Removal of activated lead-ins in the concrete.

As the cut-out blocks were being pulled out, it became clear that they could not all be removed. This was due to uneven cutting on the inside of the tank in the lead/aluminium part, as described above. Consequently, it was decided to cut the blocks loose as part of process step 4 of the work. The blocks with tubes could then be removed while performing process step 6 and removing the active concrete.

Figure 61. Reactor tank seen from the inside during the cutting of horizontal tube blocks.

Process step 5, Demolition of non-activated material from reactor block, lower part

The outer and lower part of the non-activated concrete was demolished using a hydraulic hammer on a remote-controlled mini-machine, yet bigger than the one used for the upper part of the structure.

The existing circumference of the reactor block was measured by a surveyor to determine the benchmarks for ongoing measuring of the removal of concrete and to ensure that active and non-active material would be separated.

For visual recording of progress and dividing line, a number of vertical holes were drilled in the block. These holes were drilled just in front of the dividing line.

The steel cover on the outside was demolished first, so that the concrete debris was able to fall out. Reinforcement bars and pipes were removed on an ongoing basis.

Concrete and pipes were handled as "white waste" and checked by AHF prior to disposal.

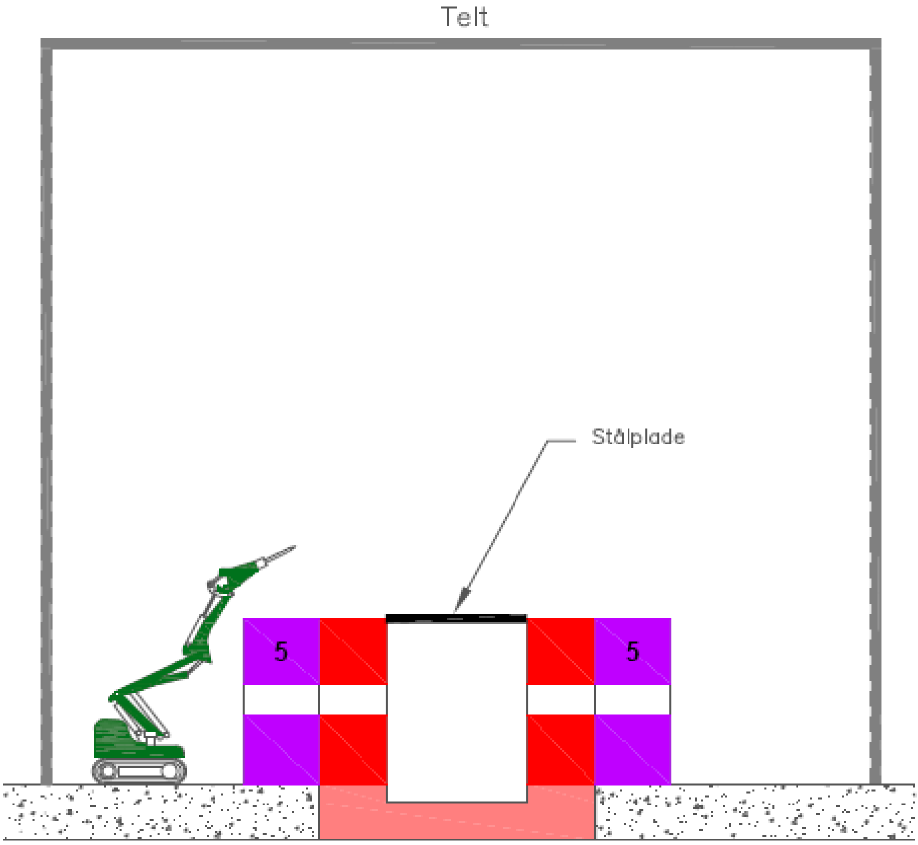

Figure 62. Process step 5, Demolishing of non-activated material from the reactor block, lower part.

Figure 63. Process step 5 completed. Activated concrete part "exposed".

Process step 6, Demolishing of activated material from reactor block, lower part

After completing the breaking-up of the chimney and shoulder and removing the non-active concrete and pipes on the lower part, the inner active parts from elevation level +3.5 to 0 were demolished.

Concrete break-up work was done using a remote-controlled mini-machine (Brokk 130) fitted with a hydraulic concrete hammer. The aluminium parts, the lead cover and the reinforcement bars were uncovered and removed on an ongoing basis. Pipes were also collected.

The aluminium reactor tank itself was cut on an ongoing basis using hand-held tools from elevation level +3.5 to 0 in suitable pieces that would fit directly into DD's containers.

All aluminium, reinforcement bars and concrete debris, etc., from this process step were handled as radioactive waste.

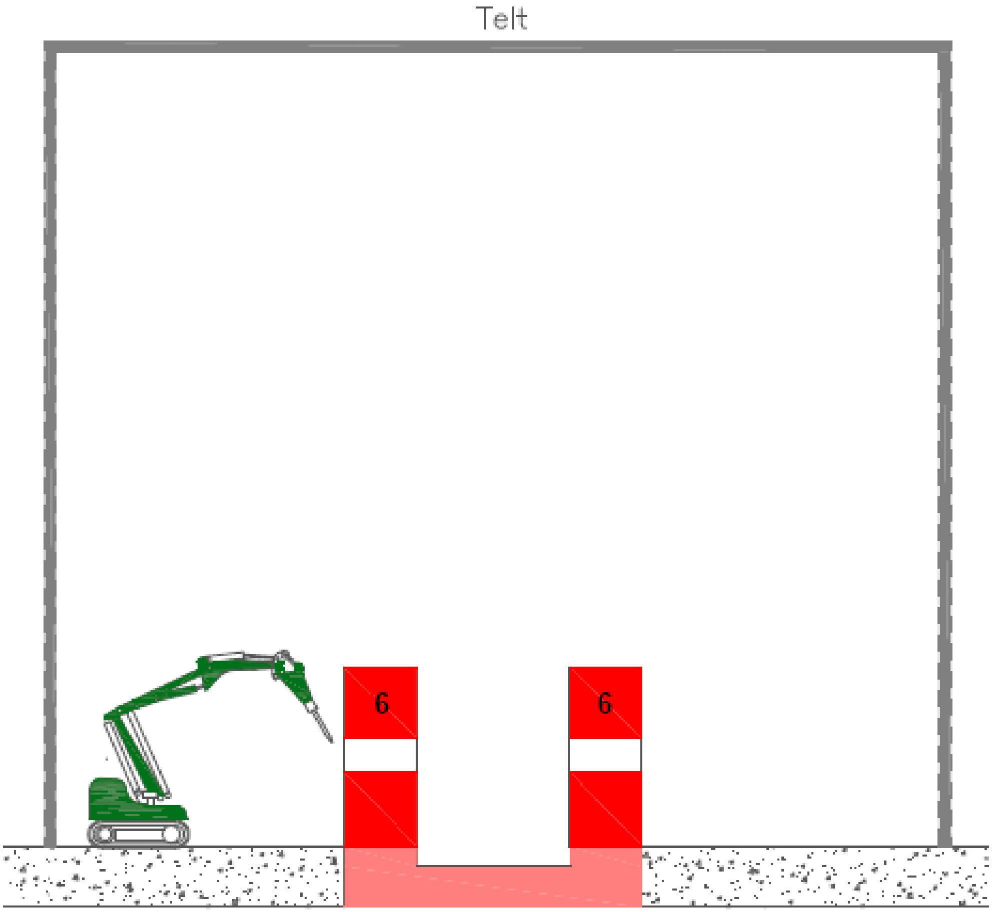

Figure 64. Process step 6, Demolition of activated material from reactor block, lower part.

Figure 65. Demolition of activated part of reactor block. Local extraction system fitted on a hydraulic hammer.

Process step 7, Removal of activated concrete from floor

The activated part of the floor underneath the reactor was also removed by being broken up with a remote-controlled small-size machine. The floor towards the basement was 60 cm thick generally in the hall, but directly underneath the tank, however, it was only about 35 cm. The floor was made with strong steel reinforcement with up to 40 mm Tentor reinforcement. Since the mini-machine (Brokk 130) was not placed directly on the part of the deck that was being demolished, no additional propping up of the floor section underneath the tank was made in this process step. All concrete and other materials from this process step were handled as radioactive waste in accordance with the definitions.

After the break-up work on the principally determined active part of the concrete structure had been completed, careful control measurement was made on the remaining part of the floor deck and the concrete structure. This showed that all active part of the structure had been removed, as foreseen. However, a ring pipe system (cooling water) found in the peripheral area was seen to be contaminated on the inside. This was thus broken up and removed as radioactive waste. It was also found out that one pipe going from the ring pipe system around the reactor down into the primary cooling system in the basement also had contamination on the inside. Since this pipe section had been cast on site when the reactor was built and led via the load-bearing wall structure into the basement and had a number of cast-in bends, it was decided to leave this pipe section in connection with the lowering of the building's classification. However, the pipe section was cleaned in that loose particles were vacuumed off and the section was thoroughly flushed with water. This led to an acceptable contamination level for the lowering of the classification (cf. chapter 11).

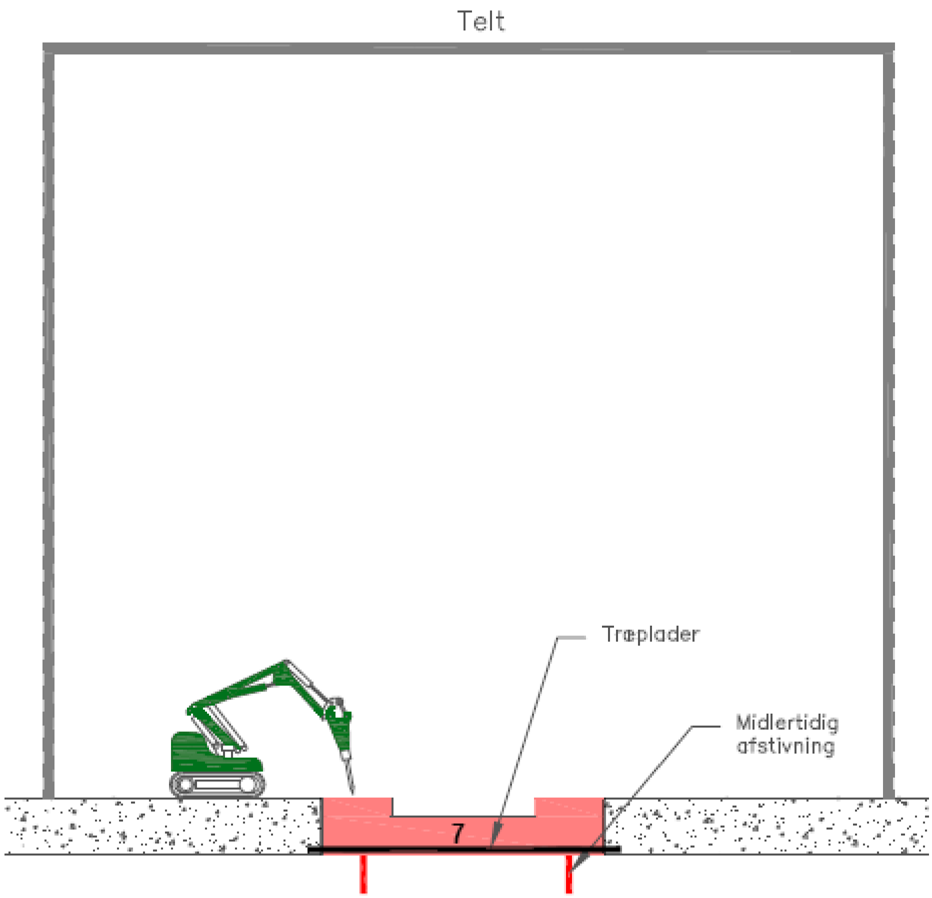

Figure 66. Process step 7, Removal of activated concrete from floor.

Figure 67. The reactor has been removed. At the back is the southern tent wall with extraction units ("environmental boxes").

Demolition checks

After process step 7 had been completed, DD prepared a control plan to ensure that all activated parts of the concrete structure had been removed in accordance with the assumptions (cf. section 5.4.1). The broken-up area in the concrete floor did not correspond completely to the predefined profile. However, as regards the future use of the hall (cf. section 11.2), the project management wanted to avoid cutting off concrete from the primary static building structures. Consequently, a plan was made for taking drill core samples in the floor area around the reactor. The special focus was on checking the area outside the thermal column, where a higher flux of thermal neutrons from the reactor core had existed than underneath the concrete shield. This work was carried out by DD.

Figure 68. Taking of drill samples from the concrete floor.

The results of the drill core tests are shown in chapter 7. All samples taken show that no active concrete had been left behind, so the concrete demolition contract work could be concluded as planned.

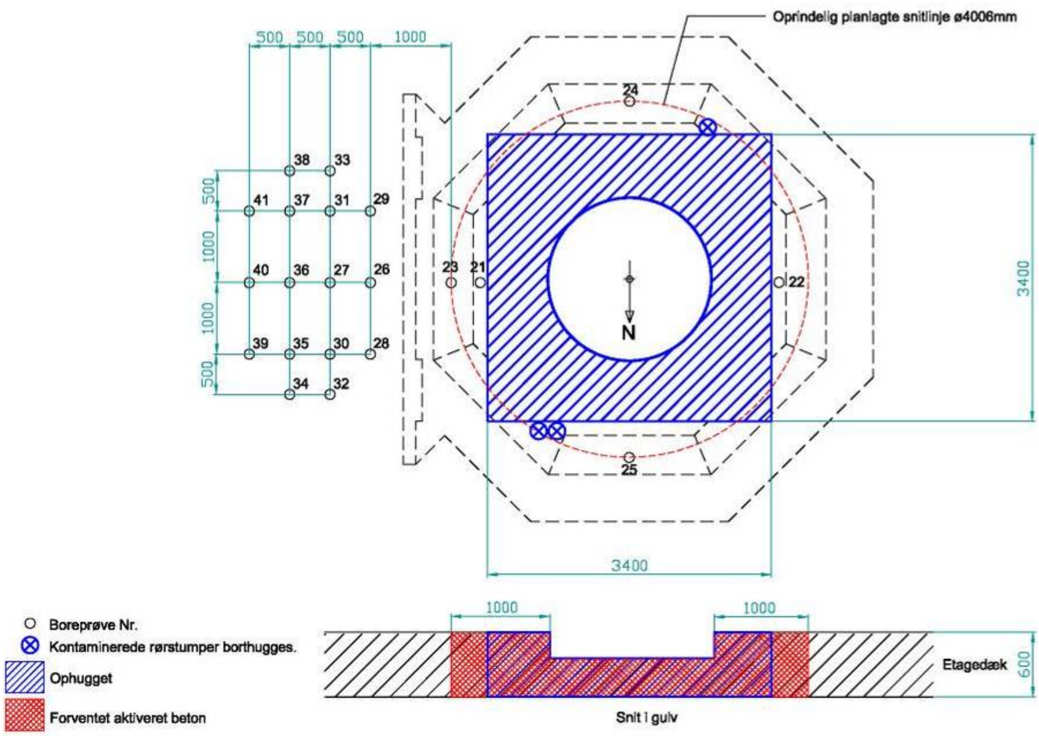

Figure 69. Plan for drill core samples for checking the concrete break-down.

5.4.2.4 Disposal of concrete and materials

Radioactive concrete

As stipulated in the specification of requirements for the concrete demolition contract (5.4.2.1), the active concrete was separated from the non-active part. The process chosen guaranteed this, as described above.

Since the active parts of the concrete had been pre-classified as radioactive waste, no further checks were made in connection with the transfer to DD's intermediate storage facility. However, checks were made and radiation levels were logged in and on the steel containers used.

For practical reasons it was decided that all cast-in pipe sections from the concrete were to be disposed of as radioactive waste. This was because most of the cooling pipe system was contaminated on the inside and because the diameter of most of the pipes was small. Also, the volume was relatively modest. Aluminium pipes were removed completely from the concrete and disposed of in separate containers. This was done out of consideration for a potential reaction between concrete and aluminium that could emit hydrogen.

Cleared concrete and other items

Aluminium from the tank, reinforcement bars and debris from the biological shielding were partitioned into suitable sections and were basically handled as non-active waste to be disposed of as building waste, cf. the applicable municipal regulations, i.e. mainly disposal for reuse.

However, all material to be transported away from DD was subject to control measurements by DD's health physics staff and recorded, before the project manager gave the final permission to take the material away. The check was made directly in the container before the material was taken away. For this purpose, an approval procedure with pertaining documentation was established; the documentation had to be signed by the project manager or a person appointed to be responsible for this sign-off. The contractor was obliged to hand over records specifying the haulier, the volumes carried and the final destination of the material.

The upper part of the aluminium reactor tank was removed and decontaminated at DD's own decontamination facility. Subsequently, these items were cleared for disposal.

Small-dimension pipe sections that could not be checked on site for any possible inside contamination (typically with a diameter of less than 100 mm) were removed from the biological shield structure. Removed items were measured separately at DD's clearance laboratory.

Figure 70. Cast-in pipe sections from the concrete structure removed for further checks.

5.4.3 OSH plan for demolition work

The demolition contract comprised primarily concrete demolition work and the handling and disposal of broken-up materials. The special aspect of this contract was that parts of the structures were radioactive which meant that dust and water could lead to a risk of unwanted spreading of radioactive materials. This represented a big challenge for both DD (the owner) and for the contractor's planning, choice of method and documentation, including OSH work.

Basically, the demolition contract comprised the following elements:

- establishment and operation of a work site and the welfare measures associated with it;

- demolition of reactor block DR 2;
- establishment and operation of environmental measures associated to the demolition work;
- disposal of pure (non-activated/non-contaminated) demolition products;
- handling of contaminated/activated demolition products that will remain on DD's premises.

It was thus decided to draw up an OSH plan for the employees in connection with the demolition of the reactor block. The responsibility for making this plan rested with the owner. The plan applied to all parties involved in the demolition contract.

OSH planning, including the preparation of an OSH plan, was carried out by the owner (DD). DD also provided all relevant information to the contractor on internal rules and procedures, risk areas, etc., before work started.

DD handled the following obligations during performance of the contract:

- preparation of an OSH plan,
- updating of the OSH plan,
- coordination of OSH efforts,
- delimitation of OSH efforts.

The contractor registered the work site with the Danish Working Environment Authority. In addition, it was decided that the contractor would give DD the names of all employees in writing and appoint safety representatives.

OSH meetings were held every other week, at which the OSH plan was updated and revised, if required. The safety representatives were obliged to make sure that the plan was accessible to all the tradesmen whom they represented and who would be coming to the work site. The safety representatives were also responsible for ensuring that the plan had been updated with the latest revised appendices for the tradesmen they represented.

The OSH plan for demolition of the reactor block was prepared by DD with inputs from the contractor and was subject to ongoing updates based on close cooperation. DD appointed a safety coordinator who handled the daily management of the owner's obligations and had ongoing contact with the contractor's safety representatives.

The plan contained a list of contacts with DD, the owner, and with the contractor, plus all employees involved. The work site layout was described together with applicable rules for employees on the site. The report included time schedules plus appendices with drawings and plans.

The OSH plan was drawn up in accordance with the rules of the Danish Working Environment Act, as specified in the Working Environment Authority's At-guideline no. F.1.2 (March 2003) *Responsibilities and obligations of the Building owner*.

The plan contained descriptions and specifications in regard to the following elements, among others:

- coordination of OSH work
- list of names, employees from DD and external contractors involved
- OSH organisation
- OSH meetings and cooperation
- work site layout
- access roads and parking
- emergency response and assistance
- establishment and organisation of the work site, plus provisions for the operation of the work site and supplies to the work site (power, water, pressurized air, ventilation), as well as work site (tent) access
- requirements made on employees
- waste management
- control measurements
- requirements as regards the natural environment
- cordoning-off and covering measures during work performance
- keeping the work site clean
- time schedules.

In addition, the OSH plan contained a number of details in the form of appendices and drawings in such areas as:

- the OSH organisation
- the DR 2 building and surrounding area (drawings)
- the "KMA" plan (the contractor's *Plan for managing quality, the environment and the working environment, including a statement of removed material volumes)*
- OSH situation for visitors and external employees
- control chart for removing decommissioning waste from DR 2
- control chart for work performance
- control chart for start and end of a working day
- work descriptions for demolition works.

The OSH plan was accessible at the contractor's and the owner's and was also available on the work site.

When demolition was performed, no observations or accidents were reported. The demolition work was completed to DD's full satisfaction.

5.4.4 Doses during the demolition of the concrete

As is apparent from Table 11, page 106, the doses received by DD's own employees during concrete demolition were limited. One health physics technician (dosimeter number 917) received 0.2 mSv, when the person assisted some external employees who needed to access the tank (see below). Otherwise, the DD employees only monitored the demolition work from a distance. External employees, on the other hand, received larger doses. These doses were received primarily by MT-Højgaard's employees while they worked to cut out the tube liners from the concrete blocks. On several occasions, they had to enter the tank, where the radiation level was up to 500 μSv/h in several places. Their stay was restricted to 10 minutes at a time, which helped to keep the total doses low. The highest dose received by any individual was 1050 μSv spread over a period of four months. All in all, the concrete demolition work resulted in a collective dose of 4.8 man-mSv.

5.5 Decontamination works

Waste items with loose surface contamination were basically classified as 'yellow' waste and were sent from the decommissioning site to DD's decontamination facility. At this facility, items with a surface of approx. 1x1 metres can be cleaned manually using a glass-bead blasting agent.

Based on the waste items recorded in ADS (cf. chap. 8.2), 100 items were characterised as 'yellow' waste for decontamination, representing a total volume of just over 30 tonnes. Most of these items could be cleaned and have been cleared for disposal as regular waste. The remaining, small quantity still awaits cleaning at DD's decontamination facility.

Of the items originally classified as 'yellow', only nine have had to be reclassified as 'red' waste following non-successful cleaning. This represents a total of three tonnes, i.e. 10% of the total volume of 'yellow' waste. These items are all made of steel and aluminium; it has turned out that these could not be decontaminated satisfactorily. Some of these items are pipes from heat exchangers (cf. section 5.3.2).

In addition to waste items, a few tools and machinery items both from DD and from external contractors on the project have undergone decontamination before clearance; in some cases all that was required was a normal wash-down (into an active drain). In conclusion, therefore, DD's decontamination facilities must be said to have worked satisfactorily.

As shown in section 8.2.2 of this report, 420 tonnes of cleared waste has been reported at this time. As mentioned, most of the waste for further processing and clearance measuring (20 tonnes) will end up being cleared. The total volume of cleared waste for disposal or reuse as non-radioactive will thus total 440 tonnes.

5.6 Stand-by tank facility

The buried stand-by tank facility consisted largely of three 20 m^3 tanks, two 50 m^3 tanks and various 2", 3", and 4" pipe conduits, pipe ducts, etc. The tank facility was placed in a buried concrete structure south of the DR 2 building. Tanks 2, 3, 4 and 5 were never used while reactor DR 2 was in operation. The purpose of the tanks was to receive large quantities of contaminated water in case of abnormal events, where the sprinkler system in the hall would be triggered. Water would successively run via a spill-over system from tank 1 to tank 2, etc., etc.

Tank no. 1 was used while the reactor was in operation; it was monitored by the Waste Management Plant as regards operations and emptying. This tank was found to be contaminated and was thus recommended for subsequent partitioning. The other tanks were removed after clearance.

The measurements made on the tank facility were described in an AHF work memo of 14 May 2006 [DD-2005-0421-1], enclosed as appendix 4.

The remaining tank, no. 1, was placed in the experiments basement for partitioning with a view to being decontaminated. The tank was used for a short period in a uranium extraction project after DR 2 closed down and had a slight contamination at the bottom up to where the water level was.

Smear tests from tank 1 showed traces of ^{137}Cs, ^{60}Co and ^{235}U, while a water sample (400 ml) taken from the same tank showed traces of ^{137}Cs. It was decided to pump as much water as possible from the tank to the Waste Management Plant via the tank vehicle and to place the tank in a closed area for subsequent partitioning and decontamination.

Since the tank had an epoxy coating on the inside and was contaminated, a nibbler was chosen for partitioning of the tank, to prevent the spread of contamination via fumes and spark burns. The tank had previously been washed down on the inside and dried by the extraction of sludge.

The tank was 9000x1700 mm, made of 6 mm steel, with a total weight of 2,417 kg. It was nibbled into suitable pieces that could be handled by the decontamination facility. The punched-out pieces of no more than 1x1m were sorted on pallets that had side members and plastic at the bottom.

The non-contaminated pieces were subjected to control measurements on site; following a health physics assessment, they were then cleared on site. The contaminated parts were transported to the decontamination cabin where they were cleaned.

The work was done in 2007. Most of tank 1 was ready for clearance following decontamination; only a small quantity of 65 kilos of cut-offs from the partitioning of the tank was removed as radioactive waste and placed at DD's intermediate storage facility. This means that all five tanks from the tank system have been cleared and removed as regular scrap steel.

Pipeline from DR 2 to the tank facility

When the drain pipes in the duct from DR 2 to the tank facility were dismantled, control measurements were also made. Some of pipes contained soil/sludge and levels above the background levels for the area were measured. These pipes and their gutters were cut into suitable sections and packed in plastic for subsequent control measuring, possibly after decontamination. The pipeline at the reactor building was plugged with plastic at the ends. Measurements made in 2004 in the duct with a contamination monitor showed no radiation or contamination levels above the background level for the area.

Pipes and gutters have subsequently been decontaminated and cleared for regular disposal.

The duct between DR 2's reactor building and the tank pit has been bricked up at the end, at the tank pit. When the concrete duct is to be removed at a later point in time, control measurements of the concrete will be made.

6 Remaining structural components

In building 200 today, the ventilation ducts in the hall and the basement still remain. They were used during DR 2's period of operation. In addition, a few pipe sections still remain that were cast into the load-bearing structures between the hall and the basement. These pipe sections are assumed to be slightly contaminated. These parts and the mentioned pipe duct for the stand-by tank facility must be checked when they are removed in connection with the final clearance or demolishing of the building itself (cf. Chapter 11).

7 Final radiological status

Following the completion of the decommissioning work, all items had either been cleared or taken to the intermediate storage facility. Demolition of the reactor block ended when the part of the floor closest to the reactor was broken up and deposited as radioactive waste. A test programme based on concrete drill tests was made to determine how much of the floor had to be broken up. The test programme was based on method A (cf. chap. 4), which in this context means that if a drill sample is measured to be clearable, the concrete further away from the reactor core, horizontally as well as vertically, will also be clearable. The positions of the drill samples are shown in figure 69, page 89, while all the measured clearance indexes are given in the table below. Some drill samples were measured together to save measuring time. Wherever that was done, the table says so.

Table 5. Drill samples

Drill sample	Clearance index (<1 = may be cleared)
21	114.02
22	0.86
23	13.85
24	0.59
25	0.52
26	1.38
27+30+31 (upper 15 cm)	0.29
28+29 (upper 15 cm)	0.64
32+33+34+38 (upper 10 cm)	0.63
35+36+37 (upper 10 cm)	0.60

Samples 21 and 23, both taken east of the position of the reactor (towards the igloo) are seen to have a clearance index higher than 1. Consequently, it was necessary to break up more of the floor in an easterly direction. An additional three samples were taken towards the east, numbers 26, 28 and 29, to determine how much more floor had to be broken up. Number 26 also turned out to be non-clearable, although with a somewhat lower clearance index. Following yet another series of drill samples (27, 30, 31, 32 and 33), all of which were clearable, the floor was broken up to the place where these began. Another series of samples was taken even further to the east; all of them had a clearance index below 1. Samples 39–41 were taken, but not measured.

At the conclusion of the decommissioning project, no attempt was made to clear the building and surrounding area for use without restrictions. This is because it was decided to continue using the building for working with radioactive materials. On the other hand, the classification of the site has been lowered to a white radiation and contamination area, cf. appendix 3.

8 Decommissioning waste

8.1 Logging decommissioning waste

All waste material from the decommissioning process was recorded with DD's waste documentation system, ADS, on an ongoing basis.

Data logging of waste items comprised identification as well as characterisation and measuring data [5]. In addition, data were logged at the clearance lab, at the decontamination facility and when materials were transported or stored. The table below gives examples of typical data logged of a waste item at the place of decommissioning.

Just like the individual waste items, the containers in which items are packed are recorded in ADS and the items placed in a container are associated with this container in the system, thereby providing an overview of all individual items located in a given container. In its present version, ADS is not able to add the activity contents of the individual items, so this has to be done manually. When a container is moved from the facility being decommissioned to the Intermediate Storage Facility or the Buffer Hall, the dose rate on the surface is measured and entered in ADS; also, checks are made to verify that there is no contamination on the outer surfaces of the container. Furthermore, the total weight of the container plus contents is recorded; however, specification of the volumes of different materials as shown in Appendix 5 has to be done manually in the present version of ADS.

Table 6. Identification of waste item or sample (facility).

Operation	**Unique ID**	**Table (master data)**
In demolition	Facility Time Name (responsible person) Origin Description, poss. reference to design drawings Photo Weight Dimensions Material composition (down to ppm)	Facility list Persons
In sample-taking	Name (responsible)	Persons
Misc.	Comments and notes	

Table 7. Characterisation of waste item (facility).

Operation	Unique ID	Tables (master data)
Partitioning (special decontamination)	Time Locality Name If partitioned, ref. to "mother item"	Facilities Persons
Poss. partitioning of waste item	Mother ID barcode Establish daughter number ID barcodes	Waste-ID-list
Manual measurement Measuring on waste item	Time Place Name Max β–γ radiation level at a distance of 1 m max. β–γ radiation level at surface (A) Instrument Max. α–β contamination levels (B) Instrument Classification: A > 1 μSv/h, A is active (RED) A < 1 μSv/h to Clearance lab (BLUE) B > 500 Bq(β)/m^2, B is active (YELLOW) B < 500 Bq(β)/m^2 to Clearance lab (BLUE) Instrument Gamma measurement: Bq/g and counts/sec distributed on different γ-emitters. Weight of waste item	Facility list Persons Instrument type
If possibility of decontamination	Time Name Description of method	
Specially for sample-taking	Instrument Weight of waste item Sample type Position determination of waste item (coordinates) Orientation of waste item Position determination of samples in relation to item Material type	Instrument type Sample types Material types
Misc.	Comments and notes	

A total of 930 waste items were logged, including samples, for the DR 2 project. These items include main structures, e.g. a concrete structure divided into three logged items, i.e. 'chimney', outer part and inner part (active).

Activated or contaminated waste for disposal was packed in DD's specially designed steel containers (2.7 m^3) or in half-size ISO containers (6.5 m^3). All containers were closed and logged in the ADS system (cf. also appendix 5).

8.2 Logged waste volumes

Appendix 5 lists the total logged volume of waste from DR 2 in containers stored at DD's intermediate storage facility. A total of 12 DD steel containers (of 2.7 m^3 each) with activated/contaminated waste that cannot be decontaminated ('red') and 13 ISO containers (of 6.5 m^3 each) have been delivered to the storage, corresponding to a total waste volume of about 114 m^3.

From the decommissioning of DR 2, a total of 615 tonnes of waste were recorded, divided into 175 tonnes of radioactive (red) waste, 20 tonnes of waste for onward processing and clearance measuring (blue/yellow) and 420 tonnes of cleared waste. A remaining 20 tonnes of waste items are in the process of undergoing DD's decontamination and clearance process (yellow/blue). Most of this waste is expected to be cleared, bringing the final total volume of waste cleared to 440 tonnes.

Tables 8, 9 and 10 indicate the total recorded volumes of cleared active waste. In the following, a more detailed account is given of the recorded volumes.

8.2.1 Radioactive waste for disposal

Table 8. Radioactive waste for disposal

Red waste [kg]						
Items	**Concrete**	**Graphite**	**Iron steel**	**Alu.**	**Lead**	**Other**
Reactor, tank, experimental tubes	142,994		3,175	2,836	5,194	58
Igloo blocks and sliding door			85	566	8	3
Thermal column			521	700	1,241	
Graphite from DR 2		4,398				
Graphite from DR 1		518				
Foundations in basement	1,673					
Heat exchangers				2,802		
Primary cooling circuit			94			
Ion-exchanger units			554	126		88
Hold-up tank	126					
Power panels						
Stand-by tank facility						
Misc. (i.a. iron+lead balls for shielding)	309		5,013	30	503	1,067
SUM	145,102	4,916	9,442	7,060	6,946	1,216
Total						**174,682**

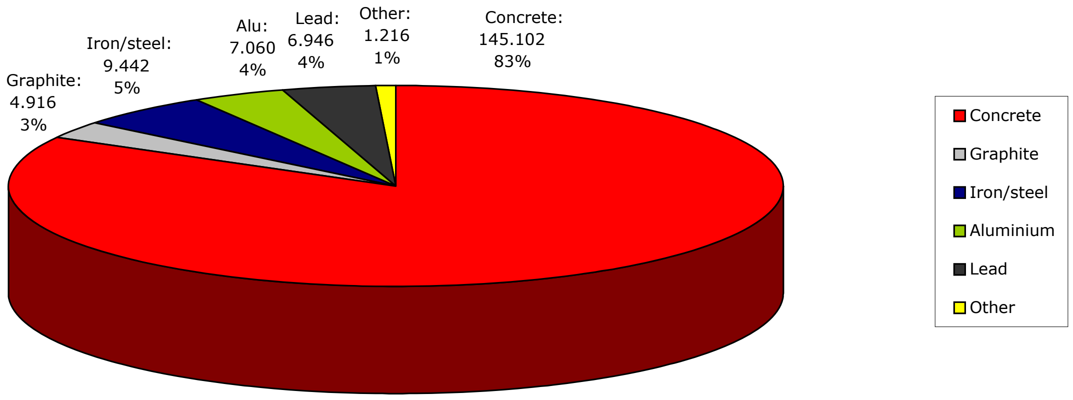

Figure 71. Division of red waste on material types.

8.2.2 Cleared waste and waste for further processing

Table 9. Waste for further processing and clearance measuements.

Blue/Yellow waste for further processing/clearance [kg]						
Items	**Concrete**	**Graphite**	**Iron/ steel**	**Alu.**	**Lead**	**Other**
Reactor, tank, experimen-tal tubes			464	481		4
Igloo blocks and sliding door	16,000					
Thermal column						
Graphite from DR 2						
Graphite from DR 1						
Foundations in basement						
Heat exchangers						
Primary cooling circuit				1,855		
Ion-exchanger units			473			
Hold-up tank				233		
Power panels						
Stand-by tank facility						
Misc.			724		84	26
SUM	16,000	0	1,661	2,569	84	30
Total						**20,344**

Table 10. Cleared waste (disposed of).

Cleared waste [kg]						
Items	**Concrete**	**Graphite**	**Iron/ steel**	**Alu.**	**Lead**	**Other**
Reactor, tank, experi-mental tubes	254,040		7,426	265		
Igloo blocks and sliding door	112,370		1,607			
Thermal column						
Graphite from DR 2		188				
Graphite from DR 1		2,126				
Foundations in basement	8,427					
Heat exchangers			774	2,775		
Primary cooling circuit			785	662		
Ion-exchanger units			734			
Hold-up tank				906		
Power panels			1,073	122	405	575
Stand-by tank facility			15,610			
Misc. (including iron and 2 old gates=7,000 kg)			8,792	127		887
SUM:	374,837	2,314	36,801	4,857	405	1,462
Total						**420,676**

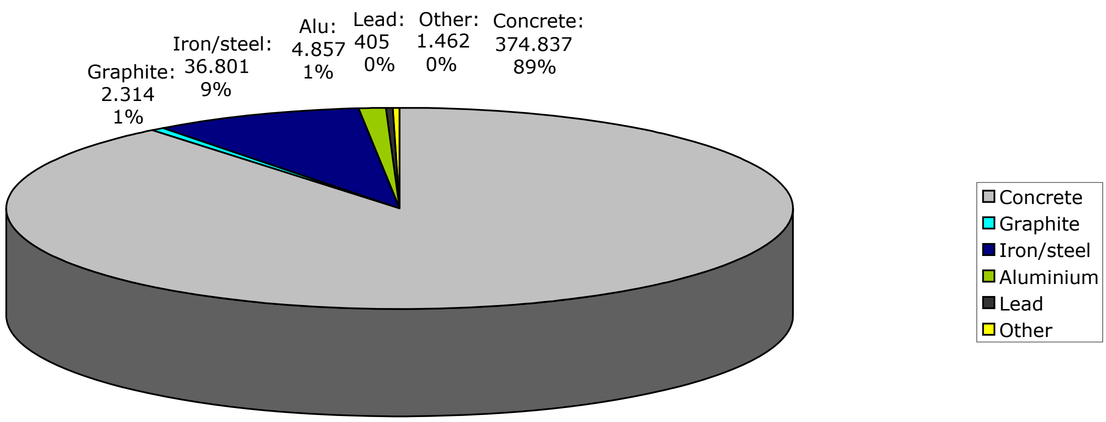

Figure 72. Breakdown of cleared waste by types of material.

At the time of writing this report, 420 tonnes of cleared waste had been logged. As mentioned above, most of the waste for further processing (blue/yellow) is expected to be cleared. The total volume of cleared waste for disposal will thus amount to about 440 tonnes.

The above overview and appendix 5 show that a minor part of the waste comes from the DR 1 reactor and other facilities from the operating period of the reactors. These items appear as waste in connection with the de-commissioning of DR 2 and are thus recorded under this project.

In addition, 20 tonnes of lead in the form of building bricks for shielding still exist. The lead is classified as 'yellow' for decontamination. The lead bricks are expected to be used for shielding in connection with future decommissioning projects. Consequently, this volume is not included in this waste calculation.

8.2.3 Conclusion

The use of the waste documentation system (ADS), which was not fully implemented at DD until the autumn of 2006, in regard to the DR 2 project meant that a DD employee had to spend almost all working time on this system. In addition, DD's health physics technicians measured waste and entered the results in ADS, and data recording was performed in labs and when waste and containers were transported. All in all, a significant and resource-intensive activity in the decommissioning process.

The total volume of non-radioactive waste from the decommissioning of DR 2 has been estimated in the project description [2] to be around 900 tonnes. This volume was based on an original idea of demolishing the building around the reactor ('containment'), including the load-bearing concrete structures in the basement underneath the reactor. As stated in section 11.2, DD intends to use the building for the handling of waste items for onward processing in connection with future decommissioning assignments. The recorded volumes of waste from decommissioning thus deviate to a certain extent from the volumes expected in the project description and these volumes are not directly comparable.

The total volume of waste material produced in the decommissioning of DR 2 is 636 tonnes.

Of the total volume of 636 tonnes of waste material, the following summarised values were calculated (rounded numbers): 552 tonnes of concrete (87%) and 7.2 tonnes of graphite (1%), 49.5 tonnes of iron/steel (8%), 17 tonnes of aluminium (2%), 7.5 (1%) tonnes of lead and a residual volume of other items/miscellaneous of 2.7 tonnes (~1%).

The project description gave a total estimate of the concrete volume from DR 2 of 276 m^3, of which approx. 260 m^3 was expected to be cleared and removed as ordinary building waste. The activated volume of concrete was thus only estimated at 16 m^3. The recorded amounts of removed – cleared – concrete are 376 tonnes.

If it is assumed, as stated in the project description, that the cleared concrete is mainly heavy concrete with an average density of 3.5 tonnes/m^3, the cleared volume of concrete from decommissioning corresponds to approx. 107 m^3. When looking at the total waste logged, appendix 5, 145 tonnes of active concrete are stored in the intermediate storage facility, i.e. just under 89 m^3 container volume. It must be stressed that broken-up concrete has a considerably higher (and varying) volume than cast concrete. If the same weight situation is assumed to apply to the originally estimated volume of active concrete, the expected volume would correspond to approx. 112 tonnes. Since the characterisation of concrete shielding in determining the active profile was not finalised until decommissioning (cf. section 5.4.1), the final waste volume is assessed to be reasonably proportional to expectations.

With a total waste volume of 636 tonnes and cleared materials share of 440 tonnes, the conclusion is that in regard to over 70% of the generated waste volume, it was possible to sort and post-process it for final clearance and disposal as ordinary waste. Since most of the waste consists of traditional building materials, the materials were removed for future re-use.

9 Monitoring programmes, measuring methods and doses

All non-standard work procedures in the classified areas were monitored on an ongoing basis in regard to doses, radiation levels and contamination levels – including air contamination. The health physics technicians were the backbone of health physics monitoring efforts. Their work consisted of radiation field measurements (standard procedure and ad-hoc), contamination measurements (standard procedure and ad-hoc), checking of technicians' electronic dosimeters, as well as control measurements of waste, etc.

9.1 Use of dosimeters

All personnel, external as well as DD staff, wore TL dosimeters and electronic dosimeters while performing their work, cf. illustration below.

Figure 73. TL dosimeter and electronic dosimeter

The use of personal TL dosimeters is required in classified areas. The dosimeter is worn on the outside of the clothes when the working day starts and is placed in a rack when the working day ends. Dosimeters are sent to Risoe DTU Department of Radiation Research (NUK) for reading once a month. DD then receives a dose list with person doses for the month in question. Doses below 0.2 mSv are not included in the dose list.

TL dosimeters have limited uses. For example, it is not possible to determine the work procedure that generated a given dose. That is why electronic dosimeters, MGP brand, are also used. When entering a classified area, the person logs the dosimeter on to the dosimeter system by entering his or her dosimeter number on a terminal. The dosimeter then starts measuring. When the person leaves the classified area, he or she logs out and the dosimeter stops measuring. A server records log-in/log-out times and any dose received.

In addition to the dosimeters for measuring full-body doses, forehead or wrist dosimeters are also used, depending on the nature of the work assignment. These are TL pellets placed in a small pocket with tape for use on the forehead or a wrist. After use, the TL pellets are read by NUK the same way as the personal TL dosimeters.

9.2 External doses

Since two types of dosimeters are used, two doses are basically stated for each person and for each work procedure (provided doses are recorded).

The collective dose in the course of the project is calculated by using the higher of the two values.

It should be noted that in a few cases the doses recorded for TL and MGP deviate considerably from one another, which could be due to different reasons. As described above, the dosimeters are used differently: a TL dosimeter accumulates radiation energy all the time, also while sitting in its rack, whereas the MGP dosimeters only accumulate during the time that the person is in the classified area. In addition, for TL dosimeters only the doses that exceed 0.2 mSv/month are recorded, whereas all MGP doses above 0.001 mSv are recorded. Finally, the position on the body may have been different in these few cases. A test has been launched to compare measured doses on the two dosimeter types at a number of known dose rates.

All external doses in this project are listed in Table 11. The highest recorded accumulated dose received by a single person in the entire decommissioning project was 1050 µSv measured on a TL dosimeter and distributed across four months. This dose was received by an external employee during concrete demolition, primarily when the liners for the B-tubes were cut. The accumulated collective dose to the external employees during concrete demolition was 3.2 man-mSv (measured on TLD, summarised figures from Table 1). The accumulated collective dose received by DD’s own employees in the whole project was 1.6 man-mSv (summarized doses – the higher of MGP or TLD – from the individual subprojects).

DD employees																
Dosimeter number	1005			210			1190		1839			917			1714	
Sub-project	MGP	TLD	Special	MGP	TLD	Special	MGP	TLD	MGP	TLD	Special	MGP	TLD	Special	MGP	TLD
Removal of S-tubes	1															
Removal of B-tubes	5		200/200/-			200/200/-										
Graphite	36			95	250	150/250/100	59		33		0/0/-	48		0/0/-	6	
Lead nose	68	100*	400/250/-	72	150*	250/200/-						6			11	
Grid plate	85	200*		92	200*										13	
Concrete demolition				1								1	200			
Sum	195	300	600/450/-	260	600	600/650/100	59		33			55	200	0/0/-	30	

DD employees								
Dosimeter number	1816		1460		197		1865	
Sub-project	MGP	TLD	MGP	TLD	MGP	TLD	MGP	TLD
Removal of S-tubes								
Removal of B-tubes								
Graphite	6		2		53		29	
Lead nose	3				27	200	2	
Grid plate					5		3	
Concrete demolition								
Sum	9		2		85	200	34	

External employees in connection with concrete demolition

Dosimeter number	78	80	66	118	74	61	72	77	122
MGP	0	0	40	12	158	61	9	183	0
TLD	250	200	1050	250	400	200	200	400	250

Table 11. External doses given in μSv.
In addition to MGP and TL dosimeters, wrist and forehead dosimeters were used in certain operations. In the table, these are listed under “special”. There are three numbers under “special” in the format <right hand>/<left hand>/<forehead>. A “-” means that the dosimeter in question was not used. For example, 200/200/- means that both hands received 0.2 mSv, while the forehead dosimeter was not used.
***** The lead nose and the grid plate were removed in the same month, which means that the TLD doses covered both work operations. Here, however, they are divided into the two operations using an estimate based on the MGP doses.

9.3 Internal doses

All DD employees handed in a urine sample once a month for an analysis of internal doses. During concrete demolition, the external employees also handed in urine samples. Measurements for β and γ were made at NUK, Risoe. No internal doses were registered during the decommissioning of DR 2.

9.4 Monitoring of air contamination

Monitoring for any air contamination (both α- and β-contamination) was carried out using a Continuous Air Monitor (iCAM) in the reactor hall throughout the decommissioning project, but no air contamination was found other than the presence of radon and radon daughters. In March 2007, the existing monitor was replaced by a newer model. Measurements from 2006, i.e. during stripping of the reactor, are available as spreadsheet files, whereas measurements from January 2007 onwards were included in the quarterly reports to the National Institute of Radiation Protecion, SIS.[13] One example of a presentation of iCAM measuring results is given in the figure below (last half of May 2007).

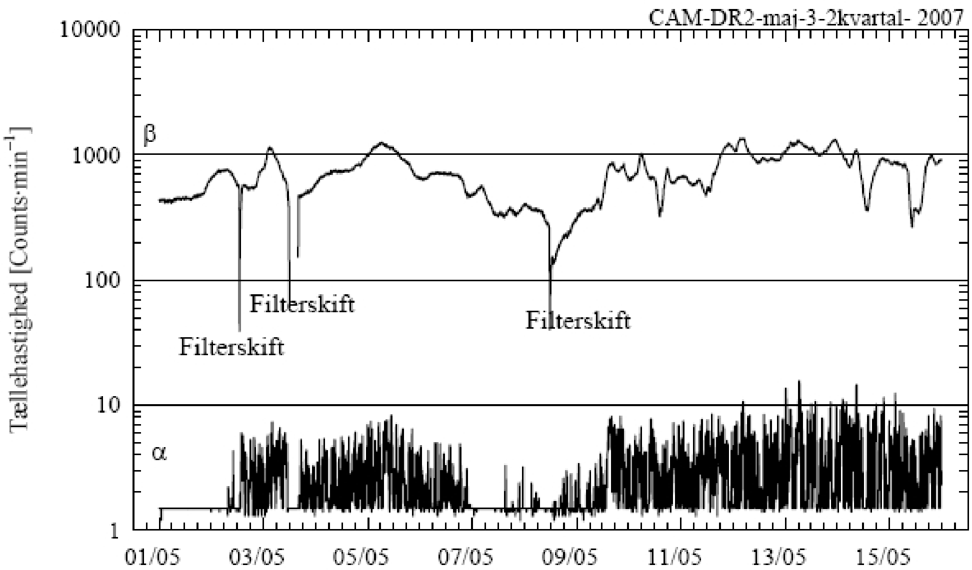

Figure 74. Presentation of iCAM measuring results.

The upper part of the figure shows the development of β-contamination, while α-contamination is shown below. Because of variation in the air content of radon(daughters), the lines are not horizontal. Had there been any β-contamination over and above the natural level, the graph would rise to a higher level without dropping back down, since the existing radionuclides at DR 2 had long half-lives if compared with the service life of an iCAM filter. The three sharp dips in the β-curve, marked "Filterskift", are due to change of filter in the iCAM.

[13] Reports DD-I-26(DA), DD-I-28(DA), DD-I-30(DA) and DD-I-31(DA) *Health physics measurements of nuclear facilities and laboratories on the Risoe site (in Danish).*

During concrete demolition, the iCAM measured in the hall outside the tent, i.e. in the same room where the ventilation air from the tent was discharged. The results from the iCAM measurements during concrete demolition (April 2007 - December 2007) were all included in the quarterly reports. No increased air contamination was observed during project execution. The fact that no increased air contamination was measured shows that the tent and ventilation, including the discharge filters, worked effectively. This can also be seen from the fact that the HEPA filters from the tent ventilation discharge were eligible for clearance, cf. the quality manual of the clearance function, when demolition had been finalised.

9.5 Monitoring of radiation and contamination levels

Throughout the decommissioning project, the DR 2 building was classified as a radiation and contamination area. Normally, the contamination area was classified as blue, but when the non-clearable concrete was broken down, the tent was classified as a red contamination area. The areas were subject to ongoing monitoring by means of standard and ad-hoc smear testing as well as radiation measuring. The results can be seen in the quarterly reports sent to SIS and as weekly measurements. Throughout the decommissioning period, there was compliance with the threshold values of the different radiation and contamination areas. In addition, a guideline was used stating that additional cleaning must be performed in a blue contamination area if the level exceeds 100 Bq/m^2.

Concrete demolition was done by external workers. The workers were given a half-day course in health physics and in the significance of the presence of radionuclides in regard to performance of the work. This may have been crucial in ensuring that no contamination spread from the tent to the surroundings.

10 Abnormal events

In the decommissioning period, there were no abnormal events of any major significance. In a couple of cases, however, there were a few surprises, e.g. when drill cores were removed for characterisation and when igloo blocks were dismantled.

Drilling sludge

In connection with the drilling of core samples in the concrete structure to determine the active profile of the reactor block (cf. section 5.4.1) a cast-in cooling pipe was hit by the drill. The pipe had been dismantled in the equipment basement, but had not been plugged. The result was that a small amount of drilling sludge ran out in the basement. It turned out that the drilling sludge was active, probably coming from the activated concrete.

It was possible to absorb the drilling sludge immediately and carry out cleaning. However, this experience meant that a keen eye was kept on the drilling process in subsequent drills.

This experience, together with the experience gained in the DR 1 project, contributed towards reconfirming the decision not to use water in the process of demolishing the reactor block (cf. section 5.4.2.1).

Igloo blocks

As mentioned in section 5.2.2, page 27, the concrete blocks from the reactor igloo were taken down and removed. The blocks, which had been designed for removal, had never been moved during the operating life of the reactor.

When the blocks had to be dismantled, it turned out in a couple of cases that they could not immediately be separated into individual blocks. This meant that horizontal, overhead blocks, together weighing over 24 tonnes (2 blocks) could not be lifted down, since the crane in the hall has a maximum permitted lifting capacity of 15 tonnes.

To solve this problem, jacks were added. Also, work was done to split the blocks into sections. In a few cases, after splitting of the blocks it took all of the lifting capacity of the crane combined with 3 x 20 tonne jacks to partition the blocks.

Consequently, this work process required far more resources and far more time that had been assumed; furthermore, careful attention had to be paid to ensure that when this much lifting capacity was in use (over 70 tonnes), the necessary work precautions and health and safety precautions had been taken.

11 Clearance procedures / Downwards classification

11.1 Clearance of items

In regard to items where no noticeable dose rates were recorded, an attempt was made to clear these according to the principles listed in chapter 4. Most items could be measured directly at the clearance lab or using contamination monitors. One exception was the concrete block. The concrete block had been exposed to neutrons; the closer to the tank, the higher the neutron flux, which means that the degree of activation declined radially from the reactor tank outwards. By taking drill samples and dividing them into smaller pieces it was possible by means of gamma spectrometry measurements at the clearance lab to decide where the limit between clearable concrete and non-clearable concrete ("red concrete") was in the reactor block. This means that method A for clearance by means of sampling has been used: If at the given distance from the core the concrete could be cleared, all concrete located further away from the core could also be cleared. Additional measurements, apart from control measurements, were not necessary (cf. appendix 6).

The number of drill samples and their location was predetermined so that the activity distribution in the whole reactor block became known with adequate accuracy. Near the B-tube liners additional drill samples were taken, since the concrete was more activated along these liners.

In the break-up work, the concrete was broken up to the dividing line between the clearable and the non-clearable concrete, as described in section 5.4, and the clearable concrete was carried away as building waste. However, control measurements were made of each container in the form of both radiation measurements and contamination measurements. On one occasion, it was discovered in this way that an activated pipe section had been placed in the container by mistake.

11.2 Change to the final condition of the DR 2 decommissioning project

In the original project description for decommissioning of DR 2 [2] chapter 5.11 says that the end goal for clearance measurements, and thus for the project, is clearance for use without restrictions. However, DD identified a need for reloading and handling facilities for radioactive items, and DR2's reactor hall could be used for this purpose. Furthermore, the basement facilities in the building (building 200) may serve as a buffer hall for radioactive waste if it becomes necessary to use also the eastern part of building 249 as an intermediate storage facility.

Since the above-mentioned use of the hall and the changing facilities belonging to it will lead to classification as a radiation and contamination area, DD wishes the building to be designated for "continued nuclear application" after decommissioning of DR 2. Prior to this, the building was thoroughly measured and cleaned to an extent that it can be classified as a white radiation and contamination area in DD's classification system. In a white radiation area, the dose rate must be below 2.5 μSv/h, while for a white contamination area the activity level of surfaces must be below 10^4 Bq/m^2 for α-activity and less than 10^5 Bq/m^2 for β-activity. When working in white areas, there are no requirements for a special dress code or change of shoes. Consequently, such a lowering of the classification means, among other things, that it will not be necessary to impose health physics restrictions on workers when the facilities are to be converted. Furthermore, downwards classification will ensure that no significant volumes of radioactive material from the operation of DR 2 will be left behind.

DD thus wished to let the downwards classification of the reactor hall and the pertaining rooms to white radiation and contamination areas be the end goal for the DR 2 decommissioning project. Subsequently, the building will be transferred to become a facility of the Waste Management Plant.

These wishes have been submitted to the nuclear supervisory authorities in the form of an addendum to the DR 2 project description [3]. The authorities have indicated that they find the use of the DR 2 hall for the described purposes after completion of the necessary alterations to be a useful solution to the recognised need for additional reloading and handling facilities and that, as proposed, this should be done as a facility under the Waste Management Plant (BEH). On this basis, the nuclear supervisory authorities have approved the Addendum. It must be noted that the new use of the building will call for changes to BfDA [9].

Independently of this project, the plans for a building layout for the new uses will be submitted to the nuclear supervisory authorities for approval when these plans have been prepared.

11.3 Lowering the classification of building 200 to a white radiation and contamination area

The assigning of a lower classification is documented on the basis of a measuring programme that will demonstrate the probability of compliance with the above-mentioned threshold values. All floors have been measured in full, while walls and installations were measured by sampling.

None of the measured levels gave any problems for the lower classification; however, some contaminated areas were identified that need to be addressed when it is attempted to have the building cleared after use. A special focus point is the pollution with uranium after the uranium pilot experiment in the 1970s, cf. the project description [2]. This contamination exists on large parts of the floor in the experiment basement. Contamination with uranium was also found in the hall, but only in the form of a few spots of a limited size. These were removed prior to the lowering of the classification. However, the possibility of the existence of more contaminated areas underneath the epoxy coating cannot be excluded.

Some cast-in pipes were left behind in the floor around the hole that remained after concrete demolition. These pipes contain some light-coloured material, probably from the drill samples in the biological shield. The radionuclides found are thus typical of activated baryte concrete. An attempt was made to clean the pipes prior to downwards classification so as to reduce the level of radiation and contamination; however, there is probably a need for further decontamination before clearance is attempted.

Downwards classification measurements are described in a memo enclosed as appendix 3. This also contains a more detailed description of what to focus on in connection with a future clearance.

12 Lessons learned

12.1 Time schedule

The decommissioning of DR 2 was planned for the period 2005–2008. After the characterisation of the reactor and the preparation of the project description, the plan was approved by the supervisory authorities in December 2005. However, the budget associated with it did not receive final approval by the Parliamentary Fiscal Committee until May 2006, following which the decommissioning work was able to start.

When the work was started, a detailed time schedule was prepared based on the project description. The plan focussed on the biggest individual assignment: the demolition of the concrete structure. This was done because the work had to be performed by an external contractor based on a public tendering procedure. Tenders for contracts of this magnitude are comprised by the EU procedure rules and the procedure rules for inviting tenders for work for government enterprises. Also, DD had to carry out a number of activities that had to be completed before the concrete demolition contract was able to start. Consequently, this contract assignment was deemed to be the most critical in terms of time and money.

Since part of the decommissioning assignment had not been tried before, the time schedule for each activity was based on a qualified estimate. During execution, a few assignments were in fact seen to take longer, some a bit shorter, and a few assignments had to be moved in relation to the original assumptions, as illustrated in the time schedule below.

The overall conclusion however, is that the time schedule was met and that the work was done satisfactorily within the main milestones.

The project ended with downwards classification of the 'containment' building in mid-2008 and the preparation of this report immediately after. Reporting and authority approval of the report represent the finalisation of the decommissioning of the DR 2 project.

12.2 Methods and techniques

The different tools presented in the report and their practical use, advantages and disadvantages, restrictions, etc., have been deemed by DD to constitute very valuable experience. Experience and the decisions made in the project have all been reported internally. Special finds and observations have all been reported to the authorities.

At DD, planning and control of decommissioning projects are in the hands of the Project Management Section. This ensures that experience gained and knowledge from decommissioning are constantly updated and integrated into future assignments. Knowledge and experience gained in the DR 1 and DR 2 project have already been incorporated into the next project, the decommissioning of Hot Cell, e.g. in regard to the usability of tools, quality assurance and the design of work plans for the individual assignments. Furthermore, experience is transferred in that the same project manager and the same health physicist are on the Hot Cell project.

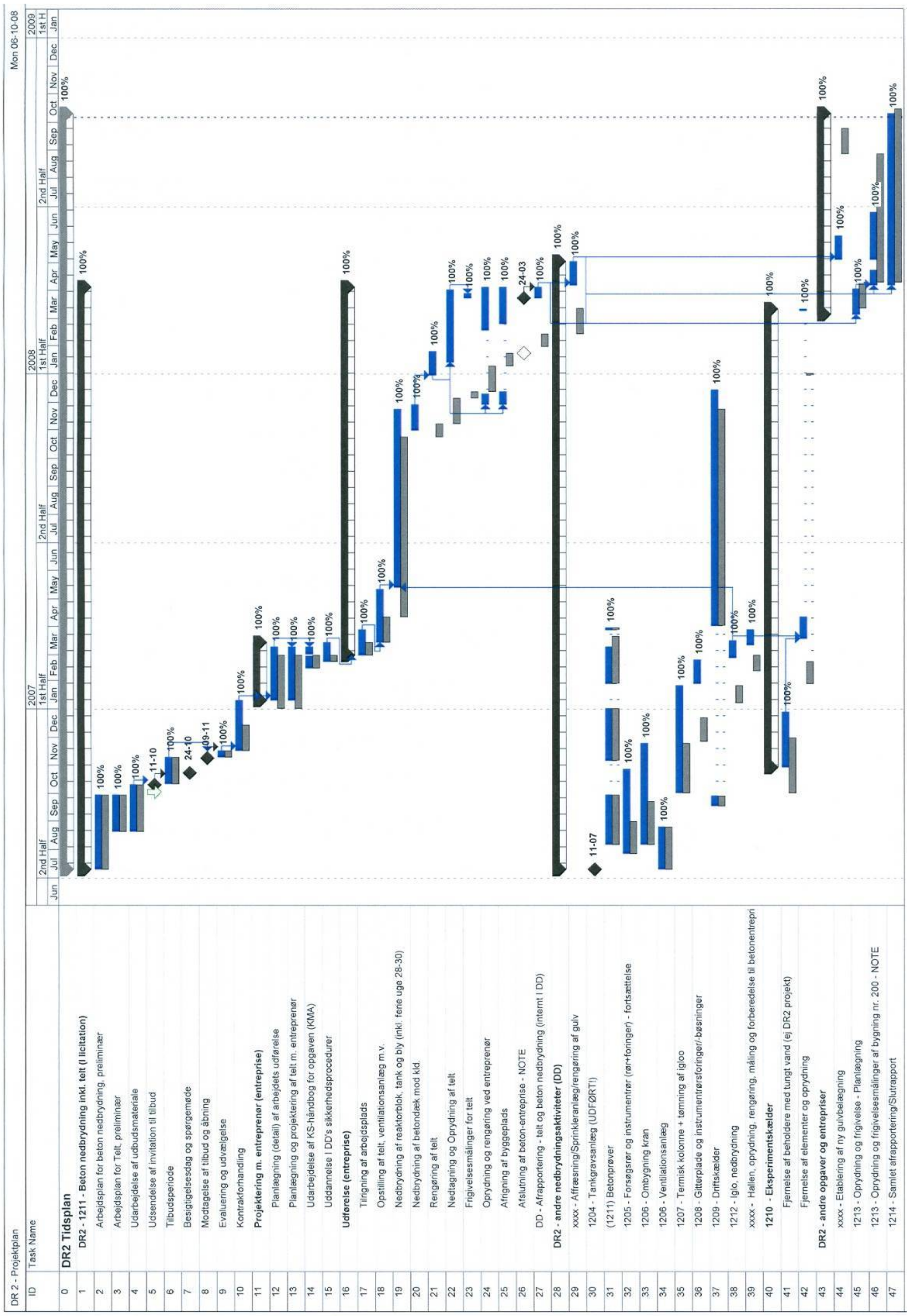

Figure 75. Time schedule for decommissioning works on DR 2 (grey = planned, blue = realised).

It has been concluded that the projects were performed according to plan and that the results were satisfactory. From DD's point of view, at the end of the day, DD itself was the "bottleneck" in different functions.

12.2.1 Waste logging

This was seen for example in the use of the waste documentation system (ADS), which had only been fully implemented in DD in the spring of 2006. At the same time, the number of individual items to be recorded and the number of data for each individual item had not been estimated prior to the project launch. For the DR 2 project, this meant that a DD employee had to work almost full time on this system. At present, DD is convinced that the ADS system and the software work correctly. In future, the need for a significant work resource for this assignment must be integrated into the planning of projects.

12.2.2 Control measurements

The procedures for control measurements of waste and equipment were changed due to the implementation of an accredited quality assurance system for the clearance of materials and equipment in the spring of 2007. This was an official requirement that created some turbulence and misunderstandings at first, until the procedures were integrated. This is not expected to have any significance in relation to future assignments.

12.2.3 Working methods and tools

Plasma cutting:

The use of plasma cutting for partitioning metallic structures turned out to be extremely useful for decommissioning purposes. The following special advantages could be mentioned:

- fast cutting,
- cutting in boral plates and composite structures made of soft and hard materials,
- low weight in case of manual work,
- hand-held and easy to fit on an extender,
- remote-control possible via extender and thus, in principle, also via a robot arm,
- high cutting speed in steel and aluminium.

However, the plasma cutter requires the necessary electrical voltage and there must be pressurised air available; furthermore, the necessary air extraction must be provided in the work area. Plasma cutting may lead to problems with monitoring the air, given the type of equipment (iCAM) used by DD. In addition, care must be taken, since high voltage and strong heat are used.

There is thus a need for local extraction at the cutting location and all employees present must wear a breathing mask with particle filter (class P3). As a positive, it can be added that skilled employees have no big problems with using the tools and that, consequently, these tools can quickly be implemented in the tool assortment. Plasma cutting is expected to be useful in other projects.

No use of water:

Prior to commencement of concrete demolition it was decided that no water would be used in the process.

Experience from the DR 1 project showed that it could be difficult to control water from demolition – wet wire-cutting – during execution, which led to cross-contamination and thus extra work.

When the concrete structure on DR 2 was characterised, it was found that the missing documentation of cast-in pipes in the biological shield and in the building caused problems when drill samples had to be taken. The samples were drilled out using water. This meant that water ran via "unknown" pipes from the hall to the basement, resulting in light cross-contamination.

It turned out that the demand not to use water in the demolition of the concrete structures made of baryte concrete did not give rise to problems in execution.

In connection with concrete demolition, a number of drillings were made in the concrete structure, each with a length of 2.5-3 metres (guidelines for separation of activate concrete) without using water.

Wire-cutting was made on the biological shield without using water. In this case, prior testing was made of different types of wire; the type chosen turned out to be very useful.

Dust emission during concrete demolition using a hydraulic hammer would typically have been controlled by spraying on water. In the DR 2 project, this was done by using local extraction placed on the demolition machine and near the work area, as well as by keeping the room well ventilated.

Wire-cutting in hard and soft materials:

All wire-cutting at DR 2 was made without the use of water; prior tests were made on the materials and types of structures to be demolished.

Wire-cutting was used for demolishing baryte concrete, as described above.

Wire-cutting was used for cutting out horizontal beam tubes, which contained aluminium, lead and concrete in parts of their structures. It turned out to be difficult to control the wires in the soft aluminium part, which led to skew cuts. Once the wire was able to "bite into" the hard concrete, the cutting line could be maintained.

When the heat exchangers were partitioned, wire-cutting was also used. This gave rise to largely no problems and reduced the time spent on this activity considerably. The work site was covered up to avoid spreading of chips from the cutting process.

Wire-cutting has the added advantage of allowing remote-control to a large extent. Once the set-up of the cutter and wire has been done, the actual cutting can be remote-controlled. The wire itself has a service life that depends on the nature of the material cut, the shape of the structure (e.g. sharp edges, composite materials, etc.) and the type of wire, etc. Overall, wire-cutting must be seen as a very useful method for demolishing nuclear structures.

Wire-cutting has not yet been tried for partitioning of concrete structures containing so-called shot concrete (steel/lead balls). This should be considered in connection with the future project at DR 3.

Contamination:

Apart from the above-mentioned examples of the use of water, cross-contamination of different areas did not occur on the DR 2 project.

Contamination in the building, especially of the floor in the hall, originated from the experiments with extracting uranium that were made after the reactor was closed down. Contamination was thus not recorded and its extent was entirely unknown. This could be because the reactor was closed down back in 1975 and that the hall made it possible to implement this type of experiment that was deemed appropriate at the time. At present, this problem is not expected to occur, e.g. at DR 3.

Tent:

Covering up the work area for demolition of the concrete structure by establishing a tent in the DR 2 hall turned to be very practical and economically manageable. At no time was any contamination measured outside the tent that came from demolition work.

The tent helped keep the work area separate from all other activities in the building. It allowed the establishment of separate lock and changing facilities and the use of special work clothes and work equipment in the work area. At the same time it was possible to establish a separate step as a material lock for checking broken-up material before they were removed from the building.

The tent design, using traditional steel scaffolding and a tarpaulin (reinforced plastic cloth) to make an airtight wall structure, turned out to be very useful and the tent was easy to maintain and clean. The structure was also relatively simple to take down and make control measurements on. The modular structure of the scaffolding and the tarpaulin division into "lanes" made clearance measurements relatively simple and quick.

Ventilation and local extraction:

The establishment of a separate ventilation system in the tent erected in the hall turned out to be unproblematic. The system featured a display for reading the current pressure level and a visual alarm; furthermore, controlling the negative pressure in the tent was also trouble-free. The use of individual extraction units worked satisfactorily. All extraction points had a three-step filter system with coarse filter (pre-filter), fine filter and HEPA filter. With the pre-filter placed so it was immediately accessible it was possible to make ongoing control measurements of the degree of contamination and any radiation level on filters. At the same time it turned out to be an advantage that most of the dust – and the contamination – deposited itself in the two outermost filters. The result was thus that all HEPA filters could subsequently be cleared, which led to savings on filter spending.

Local extraction, which was used during concrete demolition, turned out to be an advantage. The system had a central unit with bag filters followed by HEPA filters with discharge into the hall outside the tent. Local extraction was enabled at ten points in the hall, so it was possible to cover the entire work area. Direct fitting on a machine was another option.

The local extraction system gathered considerable volumes of dust in the work process. The dust from the demolition project was collected continually in fifteen 200-litre barrels with a snap-on lid and could thus be transported away straight from the extraction system. For process reasons, the approximately 10 tonnes of dust were disposed of as active waste. Finally, the bag filter was classified as active and the HEPA filter was subsequently subjected to a control measurement for clearance. The extraction system itself was cleaned and decontaminated without any difficulty.

12.3 Conclusion

It can be concluded that the project and the individual activities were carried out according to plan and that the chosen methods and techniques turned out to be useful. The time schedule has largely been kept and work has generally been carried out satisfactorily within the framework laid down.

One major experience regarding tools and methods that was gained in the DR 2 project is that dry wire-cutting is possible – also when cutting in a "sandwich" that contains concrete, aluminium and lead. Also, it was no problem to cut in pure aluminium the way it was done with the heat exchanger pipes, cf. chapter 5.3.2. Even if dry wire-cutting is more expensive because of the price of the wire and the possibility that the wire will have a shorter service life, DD's experience is that this method is preferable to using water-cooled wire-cutting, as was done on the DR 1 project.

Correspondingly, it can be ascertained that concrete demolition with a hydraulic hammer is possible without generating any dust outside the tent, even if the tent is not particularly advanced. As the process progressed, it was possible to gather a considerable portion of the dust generated by extensive use of the local extraction system. Experience also shows that it was possible to accurately position the dividing line between the part of the concrete shielding that could be cleared and the part that had to be deposited as radioactive waste.

DD has had the opportunity of sharing our experiences with the choice of method and tools with international colleagues in connection with DD's participation in an IAEA project on these questions [11].[14]

It must be foreseen that in coming projects, too, waste recording will be an assignment that requires most of the working time of a technical employee.

The conclusion is that DD will be able to improve processes regarding decision-making, e.g. in regard to the health physics situation, choice of working methods, safety requirements and determination of the types of container to be used for different materials. In brief, the organisation, pro-

[14] Innovative and Adaptive Technologies in Decommissioning of Nuclear Facilities (T2.40.07). This project ran from 2004 to 2008.

ject management and quality assurance make up a continuous process that undergoes ongoing improvement. Some of this improvement "comes naturally" in that the participating employees gain more experience, while other areas of improvement come from instructions and involvement of all relevant expertise at an early time in project planning. DD's Project Management Section works on an ongoing basis to improve and optimise the planning of decommissioning projects.

In addition to the mentioned lessons learned, a separate catalogue of experiences will be prepared; it will give more details as to the material-related, technical and tool-related experience gained in the DR 2 project.

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14 Appendices

Appendix 1	Drill cores and results
Appendix 2	Wigner energy in DR 2 graphite
Appendix 3	Assigning a lower classification to DR 2
Appendix 4	Stand-by tank facility at reactor DR 2
Appendix 5	Waste volumes
Appendix 6	Clearance report for the clearable part of the concrete block, dated 28 May 2008
Appendix 7	Drill samples from the biological shield of DR 2